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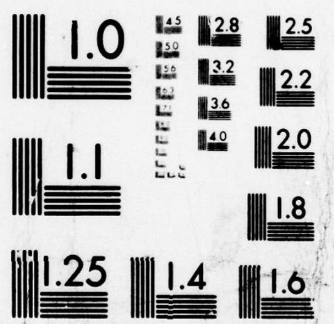

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NATIONAL BUREAU OF STANDARDS-1963-A

Report No. FAA-RD-79-81

LEVEL II

(12)

AN ASSESSMENT OF TERMINAL AIR TRAFFIC CONTROL SYSTEM PERFORMANCE WITH AND WITHOUT BASIC METERING AND SPACING AUTOMATION

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Donald Meyer

March 1979

Final Report

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16. Abstract

Basic Arrival Metering and Spacing (M&S) is being developed as an ARTS (Automated Radar Terminal System) III enhancement designed to aid the terminal air traffic controller in the functions of metering arrival aircraft prior to their acceptance in terminal airspace, sequencing them according to their estimated time at the runway, scheduling each aircraft at fix points along the arrival path to the runway arrival gate and providing control commands to assure precise and proper spacing for aircraft on final approach to the runway.

This report details the objectives, methodology, and results of recent National Aviation Facilities Experimental Center (NAFEC) simulation testing and analysis of the performance of the basic arrival M&S program performed by Sterling Systems, Inc. under contract to the Federal Aviation Administration. The analysis indicated that the distribution of error about the required separation between aircraft operating under metering and spacing was such that significant runway capacity increases could be attained while limiting aircraft separation violations on final to an acceptable level.

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METRIC CONVERSION FACTORS

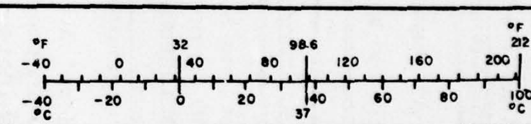
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

As part of its overall engineering and development program for terminal air traffic control systems, the Systems Research and Development Service of the Federal Aviation Administration has undertaken efforts to develop computer software to aid terminal air traffic controllers in the organization and management of flights vieing for the use of common or interfering runways. These efforts, grouped under a subprogram entitled "Metering and Spacing", are broken down into several sequential phases. The phase currently in progress is termed "Basic Arrival Metering and Spacing" and has as its objective the development of capabilities that would enable demonstration of the basic concept at an ARTS III equipped field site. Design and development of the software as well as software support during test and demonstration efforts is being accomplished by the UNIVAC Division of Sperry Rand. Assistance in review and assessment of the design, preparation of test plans, execution of tests and the analysis of test results is being provided by the National Aviation Facilities Experimental Center (NAFEC) and the METREK Division of MITRE.

In April 1978, Sterling Systems, Inc. (SSI), was engaged to assist in the evaluation of data collected during the test and evaluation efforts at NAFEC with the principal focus being on those measures most indicative of end results as relates to the operational mission of terminal ATC facilities. The test runs evaluated were carried out in June 1978. Terminal arrival operations were conducted in an ATC simulation environment without metering and spacing automation and were repeated using the same traffic scenarios with automation assistance added to the system. A complete description of this earlier effort and its results are contained in SSI Final Report, "An Assessment of Terminal ATC System Performance With and Without Basic Metering and Spacing Automation", SSI Project No. 601, August 18, 1978. In substance, the conclusion drawn from this assessment was that although anticipated improvements in overall system performance through the use of automation assistance were not demonstrated, there were strong indications that with the correction of identified deficiencies in the program and flaws in the simulation test conditions, overall

performance of the system when operated with automation assistance would be better than when operated without it.

Following these earlier activities, efforts were undertaken by UNIVAC to develop further modifications to the program. As these efforts progressed, the FAA initiated action to obtain an early indication of the effects of these modifications on overall system performance. This consisted of re-running the earlier test scenarios with the modified M&S program. SSI was engaged to analyze the data collected during these runs in terms of overall operational performance as compared to overall operational performance exhibited in the earlier runs made without automation assistance. This report contains the results of this analysis. Additionally, efforts have been made to provide sufficient background information and relevant information concerning the previous tests and measurement methods so that the reader will find reference to the previous report unnecessary.

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1. SUMMARY

The Basic Metering and Spacing (M&S) automation package has been designed with the objective of enabling demonstration of the basic concept at an ARTS III equipped field site. Toward this end, the program has been adapted to serve either of two runways, 26L or 17R, at Stapleton International Airport, Denver, Colorado.

During June 1978, a series of tests were conducted at the National Aviation Facilities Experimental Center (NAFEC) to determine the impact on overall operational performance of adding the basic M&S automation package to the existing terminal air traffic control system. The tests consisted of a series of dynamic simulations of terminal arrival operations at Stapleton utilizing the NAFEC test facilities to simulate the Denver terminal area operational environment. ARTS III equipment in the Terminal Automation Test Facility (TATF) was used to perform the data processing and display functions while the Digital Simulation Facility (DSF) was used to simulate the air situation and the data acquisition system, i.e., compute aircraft movement and generate scan-to-scan target reports.

Two different traffic samples were used. These were selected from the samples available in the TATF library and had been prepared by NAFEC personnel based on data recorded at Denver during live operations. When applied to the two different runways, and with some variations in the aircraft's times of arrival at the feeder fixes, the two traffic samples actually constitute four different traffic scenarios.

To provide a basis for comparison, four test runs (one with each scenario) were made without M&S. These runs were made with Denver controllers using control procedures commonly practiced at Denver. A number of test runs using the same scenarios were also made with M&S. Although anticipated improvements in performance were not demonstrated, these tests did serve to identify deficiencies in the design and there were strong indications that with the correction of these deficiencies in the program and flaws in the simulation test conditions, overall performance of the system would be better when operated with M&S automation assistance than when operated without it.

Following these tests, modifications were made to the program and additional M&S test runs using the same scenarios as in the earlier tests were made in December 1978 and January 1979.

The principal changes in the program involved redesign of the method of determining appropriate landing time intervals and modification of the speed monitoring and time to fly computations. The program was also integrated with the Conflict Alert (A∅.15) version of the ARTS III operational program.

In addition to the above, the wind derivation and update modules were redesigned to provide for deriving wind estimates from aircraft on profile descents (i.e., navigating with reference to VOR radials) as well as aircraft flying with reference to assigned headings. However, since these design changes had not been completely checked out and it was desired to separate the question of wind estimation accuracy from the other aspects of M&S performance, the December/January test runs were made with the wind updates disabled and the wind values input to M&S at the start of each run were the same as those used in the DSF target generator.

Data from six December/January test runs were subjected to the performance analysis. Four of these runs, each with one of the four different scenarios, were made with the traffic unmetered as was the case with the June test runs made without M&S (i.e., no control actions to absorb delay were taken prior to the aircraft passing the feeder fix inbound). The remaining two runs were made with the two more demanding scenarios. In these runs, simulation of the metering function was also undertaken to gain some initial insight of its impact on performance. As a practical matter, the tests without M&S were not rerun. Instead, the data from the June test runs without M&S was used.

The key measures of overall operational performance of the system, as used in this assessment, are landing time interval error, potential safe landing rate and potential excessive delay per aircraft. In brief, these measures may be described as follows:

- <u>Landing Time Interval (LTI) Error</u>: LTI error is the difference between the actual landing time interval and an after-the-fact determination of the optimum interval that could have occurred given the landing sequence employed, the actual aircraft performance as reflected by their track histories, and the restraints imposed by spacing minima. The standard deviation of LTI error is the basic measure of performance. It is also the most critical measure since a large dispersion in LTI error indicates that the interval between arriving aircraft must be large to minimize spacing violations. On the other hand, with a small dispersion of LTI error, compensation can be made for any value of mean error and shorter intervals may be used.

- <u>Potential Safe Landing Rate</u>: The potential safe landing rate is a function of the delivery performance exhibited by the system and the traffic mix encountered assuming a constant demand. It is intended to reflect the equivalent landing rate of the system if the system were adjusted to assure with some high degree of probability (e.g., 97 or 98%) that minimum spacing requirements would be satisfied and given a traffic mix that is a composite of the mix encountered in all the runs in the test series.

- <u>Potential Excessive Delay</u>: Actual delay is the difference between the actual time of arrival at the runway and the earliest time of arrival that could have been made good with no delay. Excessive delay is the difference between the actual delay and the unavoidable delay necessary to meet spacing requirements. The potential excessive delay is a companion measure to potential safe landing rate and indicates the potential excessive delay, per aircraft, if the system is operated to provide the potential safe landing rate.

Table 1-1 contains summaries of the numerical results of applying these measures to the individual test runs analyzed as well as the results when the runs made without M&S are combined and the runs made with M&S are combined to form larger samples. The summaries are organized to facilitate comparison of the runs made with M&S against the runs made without

Table 1-1

SUMMARY OF TEST RESULTS

INDIVIDUAL RUNS						Potential	
Date	Test Run No.	Traffic Scenario	No. Int.	LTI Error Mean	LTI Error S.D.	Safe Landing Rate	Excess. Dly/Acft.
6-07-78	[1]	A2638	32	14.22"	16.42"	29.16	32.84"
12-20-78	2C	"	23	0.09	10.04	32.52	20.08
6-12-78	[3]	A1738	35	9.26	16.92	28.93	33.84
1-12-79	4C	"	35	8.49	8.49	33.46	16.98
6-09-78	[5]	A2641	30	7.57	13.68	30.52	27.36
12-20-78	6C	"	24	-0.83	12.42	30.96	25.67
12-12-78	6D(-1)	"	27	2.93	17.91	28.47	35.82
	6D(-2)	"	25	-1.20	10.30	32.03	21.80
6-12-78	[7]	D1741	31	0.71	17.91	28.47	35.82
12-15-78	8C	"	35	4.60	6.96	34.44	13.92
12-08-78	8D(-1)	"	36	10.47	18.72	28.11	37.44
	8D(-2)	"	30	3.20	5.41	35.49	10.82

COMBINED RUNS

[1, 3. 5 & 7]	128	8.03	17.04	28.87	34.08
2C, 4C, 6C & 8C	117	3.76	10.07	32.51	20.14
5 & 7	61	4.08	16.33	29.20	32.66
6C & 8C	59	2.39	9.93	32.59	19.86
6D(-1) & 8D(-1)	63	7.24	18.75	28.10	37.50
6D(-2) & 8D(-2)	55	1.20	8.31	33.57	16.62

[ ] Indicates Test Run made without Basic M&S Automation

M&S. Odd numbers identify runs made without M&S; even numbers identify runs made with M&S. The letter suffix "C" with an M&S run number indicates traffic inbound to the feeder fix was unmetered while the letter suffix "D" indicates metering was applied.

It will be noted that two sets of results, identified as (-1) and (-2), are presented for each metered run. The (-1) results reflect performance when perturbations introduced by the metering process are included (in some instances, the delay imposed by the metering process was more than that required, thus creating a gap that was assessed as a positive LTI error). The (-2) results reflect the performance when the perturbations introduced by the metering process are removed and thus are indicative of the performance of the spacing function when supplied a metered flow of traffic.

The standard deviation of LTI error for each of the test runs is presented graphically in Exhibit 1-1. It may be noted that the standard deviation of LTI error for all unmetered runs with M&S is less than that of the corresponding run without M&S and, with the exception of the Run 5/6C comparison, the reduction is on the order of 50%. It may also be noted that the standard deviation of LTI error for the two metered runs where imperfections in the metering process were isolated from the results (i.e., the (-2) values), are on the order of 20% less than the corresponding unmetered runs. This tends to support the notion that the spacing function of M&S will perform better when some of the required delay (where required delay is extensive) is absorbed before aircraft reach the feeder fix.

The relatively poor performance shown in the (-1) results was caused by 8 instances (2 in Run 6D and 6 in Run 8D) where the delay imposed by the metering process was greater than the delay required. (Further information on this subject is contained in paragraph 6.3.)

The effect of a reduction in the standard deviation of LTI error is an increase in the potential safe landing rate. This is illustrated in Exhibit 1-2 where the potential safe landing rate for each test run is presented graphically.

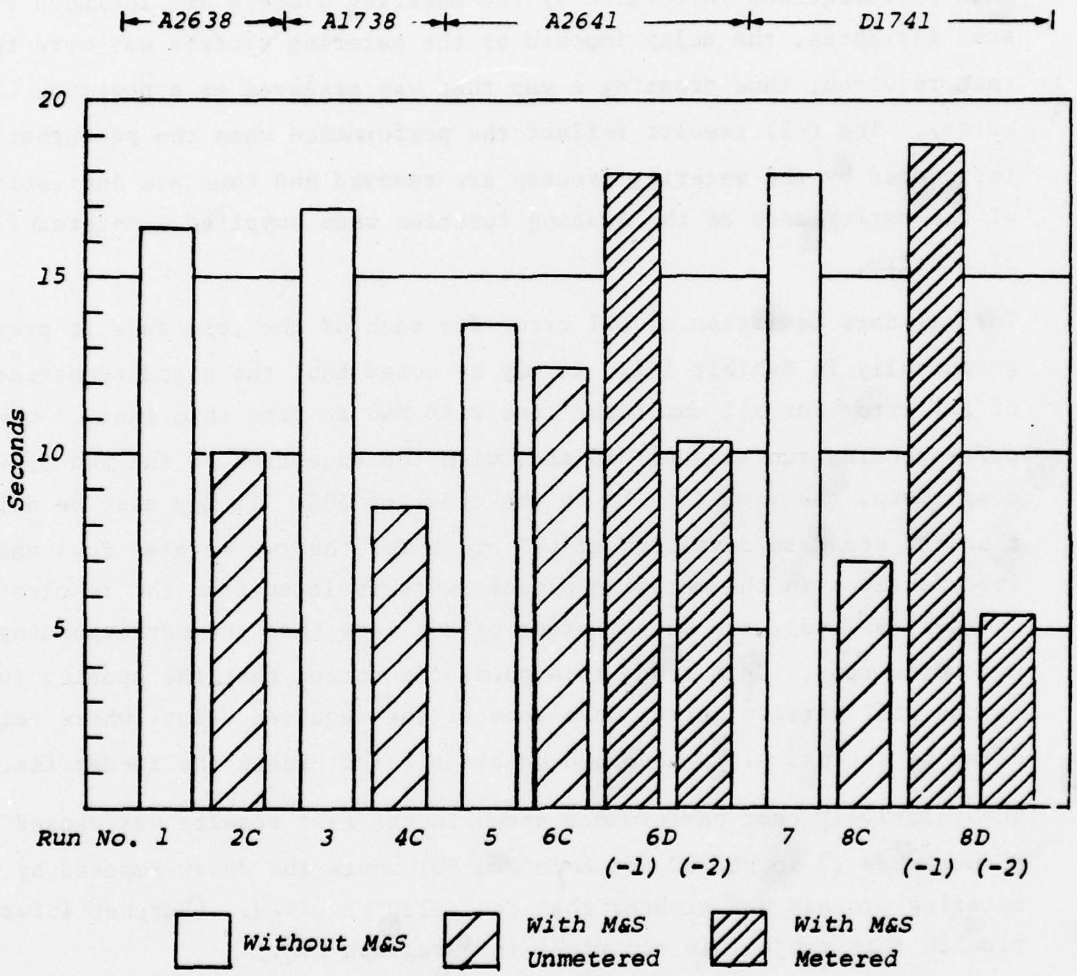


Exhibit 1-1

STANDARD DEVIATION OF LTI ERROR

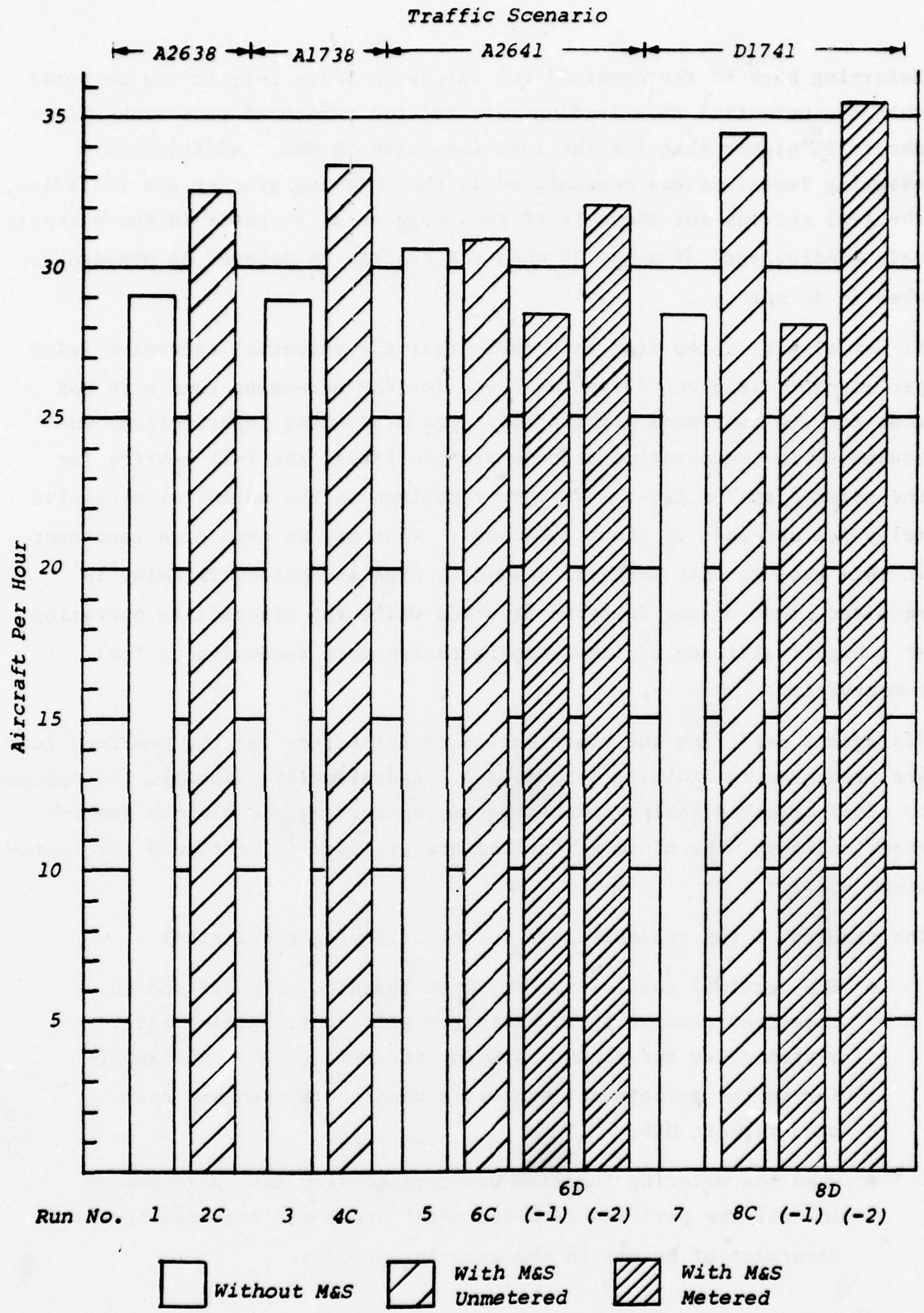


Exhibit 1-2

POTENTIAL SAFE LANDING RATES

Referring back to the combined run values in Table 1-1, it can be noted that the potential safe landing rate for the unmetered runs with M&S is about 12% higher than for the runs made without M&S. Additionally, assuming imperfections encountered in the metering process are rectified, the (-2) entries for the metered runs suggest an increase in the potential safe landing rate of about 3% when the traffic is metered as opposed to when it is not.

It may also be noted from this table that the potential excessive delay per aircraft is about 14 seconds less for the unmetered runs with M&S than for the runs made without M&S. Again assuming imperfections encountered in the metering process are rectified, the (-2) entries for the metered runs suggest a further reduction in the potential excessive delay per aircraft of about 3 seconds. What may be even more important in this case is that when the demand is high and extensive delay is required, most of the delay is absorbed while the aircraft is operating at a higher altitude and in a configuration more conducive to fuel conservation.

Histograms depicting the distribution of LTI errors for the combined runs are presented in Exhibits 1-3 and 1-4. Additionally, distance (as opposed to time) oriented tables and histograms concerning the minimum spacing experienced vs. the minimum required are provided in Section 6 (see paragraph 6.2.2).

The results of the analysis lead to the following conclusions:

- The terminal control system, when operated with M&S and an unmetered traffic flow, exhibited LTI error, landing rate, system delay and minimum spacing performance that was superior to the performance exhibited when the system was operated without M&S.

- When the metering function was applied with M&S, performance in all the performance measurement areas was degraded by the occurance of errors in the metering process.

RUNS 1, 3, 5 & 7

No. Intervals:		128
Range	:	-36/+55
Mean	:	8.03
Std. Dev.	:	17.04

RUNS 2C, 4C, 6C & 8C

No. Intervals:		117
Range	:	-26/+28
Mean	:	3.76
Std. Dev.	:	10.07

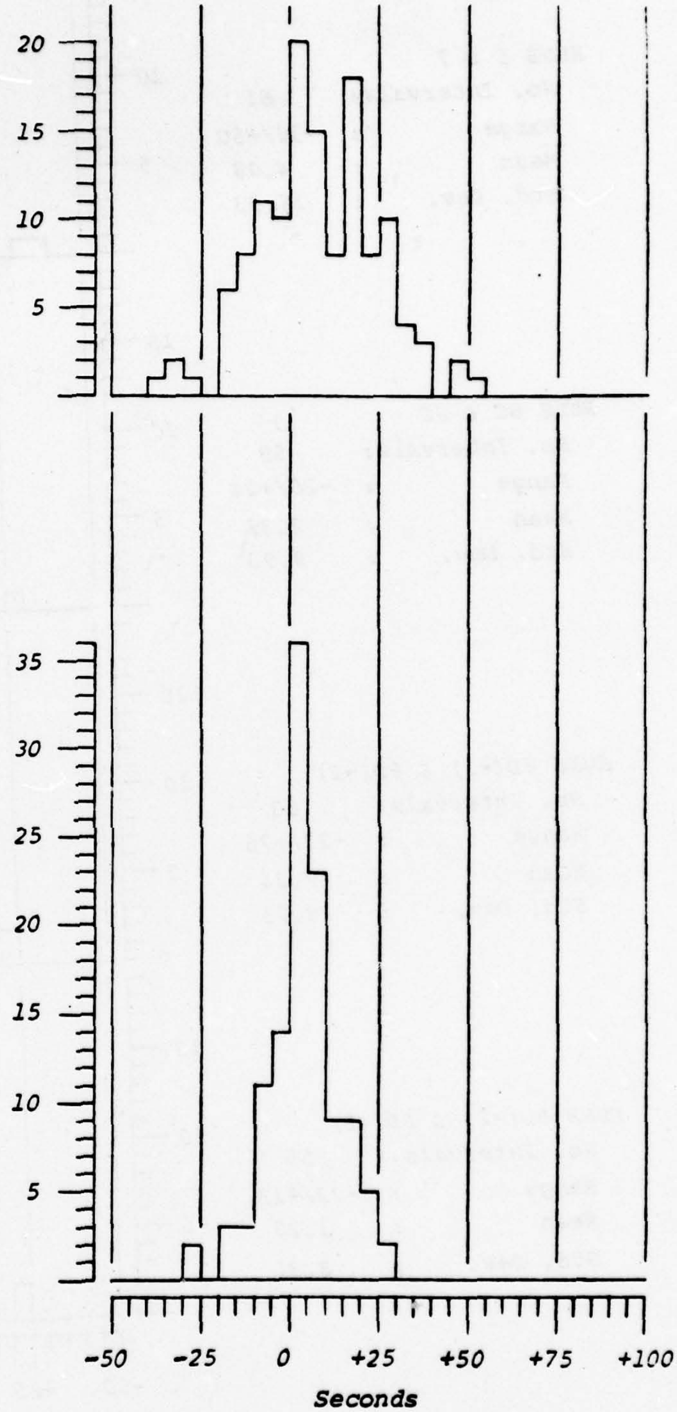


Exhibit 1-3

LTI ERROR DISTRIBUTION

RUNS 5 & 7

No. Intervals	:	61
Range	:	-36/+50
Mean	:	4.08
Std. Dev.	:	16.33

RUNS 6C & 8C

No. Intervals	:	59
Range	:	-26/+24
Mean	:	2.39
Std. Dev.	:	9.93

RUNS 6D(-1) & 8D(-1)

No. Intervals	:	63
Range	:	-23/+76
Mean	:	7.24
Std. Dev.	:	18.75

RUNS 6D(-2) & 8D(-2)

No. Intervals	:	55
Range	:	-23/+19
Mean	:	1.20
Std. Dev.	:	8.31

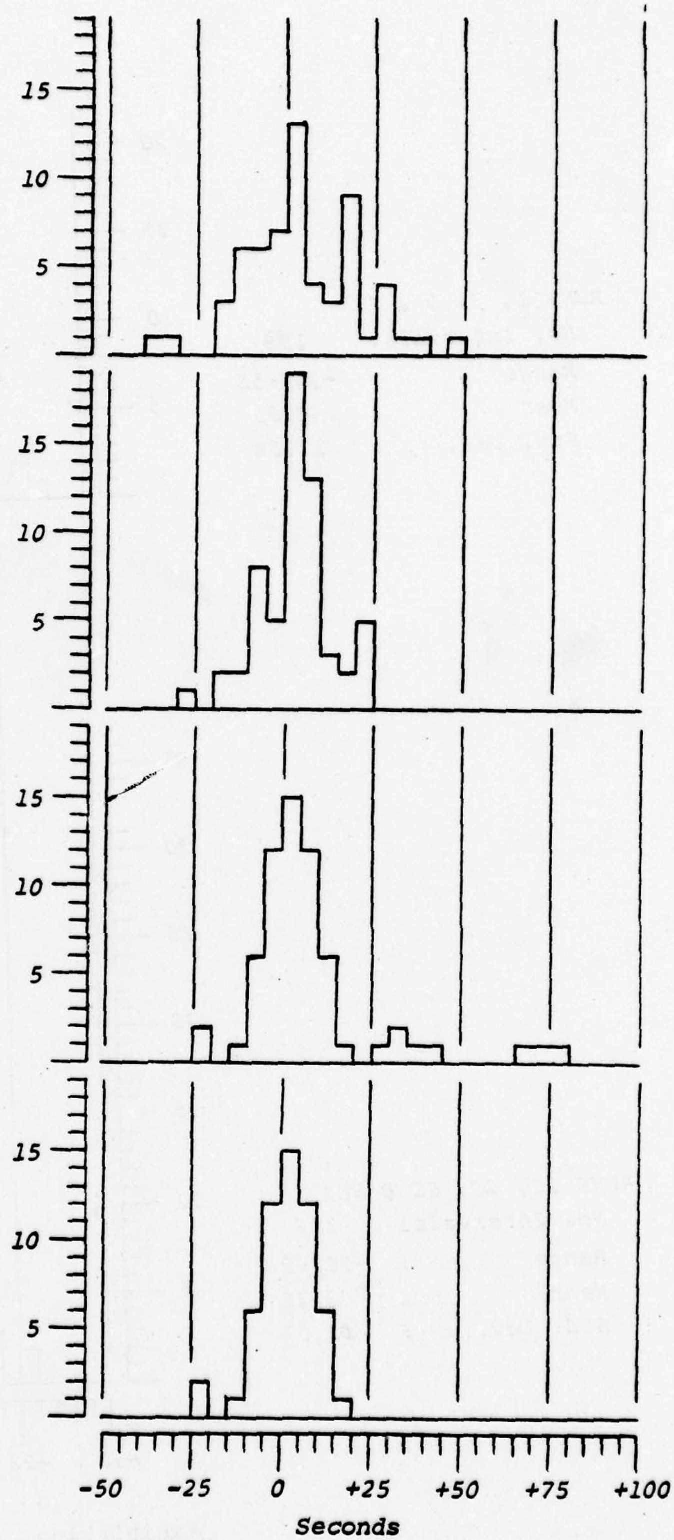


Exhibit 1-4

LTI ERROR DISTRIBUTION

- Even with the errors experienced in the metering process, system performance when operated with M&S and metering was comparable, by most measures of performance, to the performance exhibited when the system was operated without M&S.
- The most favorable results reflected for any of the test runs are those of the metered runs with M&S where the effects of metering errors have been removed. This indicates that, if the problems encountered in the metering process are rectified, the performance of the system when operating with both the metering and spacing functions of M&S will be superior to the performance realized when operating without the the metering function.

2. INTRODUCTION

2.1 General

"Metering and Spacing" is a general term covering the various activities necessary to regulate the rate, order and separation of arriving/departing flights at a given airport. Simply stated, the objective of metering and spacing, irrespective of how it is performed, is to expedite the movement of traffic to the maximum degree possible commensurate with safety and equitable treatment of all system users.

As currently performed in the field, metering and spacing functions are accomplished through the combined efforts and judgements of a team of controllers comprised of a local controller stationed in the tower cab who controls the use of the active runway(s) and arrival/departure radar controllers stationed in the TRACON who exercise control over flights that are transitioning to/from the enroute system or are otherwise operating in terminal airspace.

In IFR flight conditions, "safety" is equated to a complex, but defined, set of separation criteria governing the minimum separation that is applicable in various circumstances. Adherence to the criteria is the responsibility of the controller. In VFR flight conditions, particularly in the case of arriving aircraft, advantage is taken of the fact that pilots may be able to see and follow the preceding aircraft. The arrival controllers sequence and control the inbound flight until visual contact is established with the preceding flight in the landing sequence, at which point the pilot may be released to provide his own separation from the preceding flight. In this case, the responsibility for maintaining safe separation with respect to that flight shifts to the pilot and the amount of separation is a matter of pilot judgement. There are criteria governing the actual use of the runway and the separation required is effected by the tower controller, i.e., when it is evident that the criteria will not be met, the flight is instructed to execute a go-around (missed approach) by the tower controller.

In IFR or VFR flight conditions, "equitable treatment" is generally considered to mean first-come/first-served with, of course, the exception that flights experiencing an emergency are given priority.

It is significant to note that, in the case of arriving flights, controllability (i.e., the capability of the control system to alter the spacing between successive flights) shrinks to essentially zero as the flight approaches the final approach course. This is simply because pilots must be afforded the freedom to get their aircraft lined up with the runway and operating at a speed suitable for landing. Therefore, in delivering aircraft to the final approach course, the control system must anticipate potential closure on final approach and aim for an interval that will result in near (but not below) minimum required spacing at the point where the aircraft come closest to each other. Needless to say, this is not easy to do with precision and consistency. The difficulty becomes even more evident when it is considered that the flight characteristics of the aircraft using the system differ, separation criteria has grown increasingly complex (particularly with the addition of special criteria for wake vortex protection), and demand is continuing to increase. It is these factors that are the principle motivation for FAA's engineering and development efforts to apply automation to aid in the performance of metering and spacing functions.

With the introduction of ARTS (Automated Radar Terminal System) and various expansion packages in the field, capabilities for inter and intrafacility transfer of essential flight data and for the correlation of flight and surveillance data have become available. The objective of FAA's Metering and Spacing development program is to extend these capabilities to include decision assistance in the conduct of metering and spacing activities. The underlying premise is that by adding essential data on aircraft performance, minimum spacing requirements, maneuvering airspace available and winds aloft to the flight plan and tracking data already available in the system, the computational capabilities of the computer should make it possible to increase the precision and consistency with which aircraft can be delivered to desired points at proper intervals.

2.2 Basic Arrival Metering and Spacing

The metering and spacing development program is a multi-phase effort. The phase now in progress is termed "Basic Arrival Metering and Spacing". It's objective is to develop capabilities in a manner that would enable a demonstration of the concept at a field site equipped with the basic ARTS III

system. It is not intended as an operational version for field deployment but rather as a vehicle for determining what, if any, flaws exist in the basic concept so that any necessary changes can be incorporated in the design of the implementation version.

Development of the Basic Arrival Metering and Spacing program has progressed to the point where it is undergoing test and evaluation in the Terminal Automation Test Facility (TATF) at the National Aviation Facilities Experimental Center (NAFEC).

The design of the Basic M&S program has many facets and is quite complex. Consequently, there is no intention here of even grossly covering all of the aspects and features of the system. Rather, the intent is to give the reader a general understanding of the principal concepts and features embodied in the design of the system being evaluated. For more detailed information, the reader is referred to the design data document (Ref. 2).

The system is designed to serve either of two landing runways and has been adapted to Runway 26L and Runway 17R at Stapleton International Airport, Denver, Colorado. Provisions are additionally included to accommodate operations to an alternate parallel runway (26R or 17L) where aircraft to those runways are expected to break off their instrument approach at the final approach gate and continue their approach to the alternate runway visually.

In addition to the data available from flight plan and track data files, the program uses aircraft profile data, updated wind data, runway occupancy data, required spacing data and control geometry data in makings its determinations.

The aircraft profile data include information relative to the normal speeds, descent and deceleration rates for each type of aircraft expected to use the system along with an indication of the aircraft's weight class and whether it is in the high or low performance category.

The updated wind data are estimates of the average wind values in each of the areas flights are expected to transit. They are initially derived from winds aloft forecasts and subsequently updated by an adaptive wind routine that measures the difference between expected

and actual performance and attributes some ratio of this difference to wind effects.

The runway occupancy data are a set of estimates of the time aircraft of various weight classes are expected to occupy the runway.

Required spacing data are the minimum final approach spacing required between various weight class pairings of aircraft. They also include a minimum separation value that may be manually entered. (Normally this would be used to assure some minimum spacing above the minimum in weight class pairings in the event of adverse field conditions or to afford more opportunities for departures in the event of a long departure queue.)

Control geometry data include data defining the minimum and maximum path between the Feeder Fix and a point called the Inner Fix (Sequence Area) and between the Inner Fix and the final approach gate (Base Area). They also include information on the earliest and latest points of speed reduction, altitudes called for in the procedure and certain data concerning the final approach such as distance from threshold to Outer Marker and from Outer Marker to the gate.

The initial design was based on sequence areas that, in addition to the minimum path, included delay paths to provide controllability in the sequence area. However, during the course of the development effort, a "four poster" feeder fix concept and profile descent procedures were implemented at Denver which not only changed the location of the feeder fixes but also barred the use of delay paths in the sequence area. This new geometry, as illustrated in Exhibits 2-1 and 2-2, was added to the design. It will be noted that other than by varying the point at which speed reduction is made, which is also limited and counter-productive to fuel conservation, there is no controllability in the sequence areas.

The control geometry used in the base area is a function of the direction of entry into that area. If the entry is on the downwind leg, the delay paths have the appearance of a sliding trombone. If the entry is perpendicular to the downwind leg, the delay paths have the appearance of an unfolding fan.

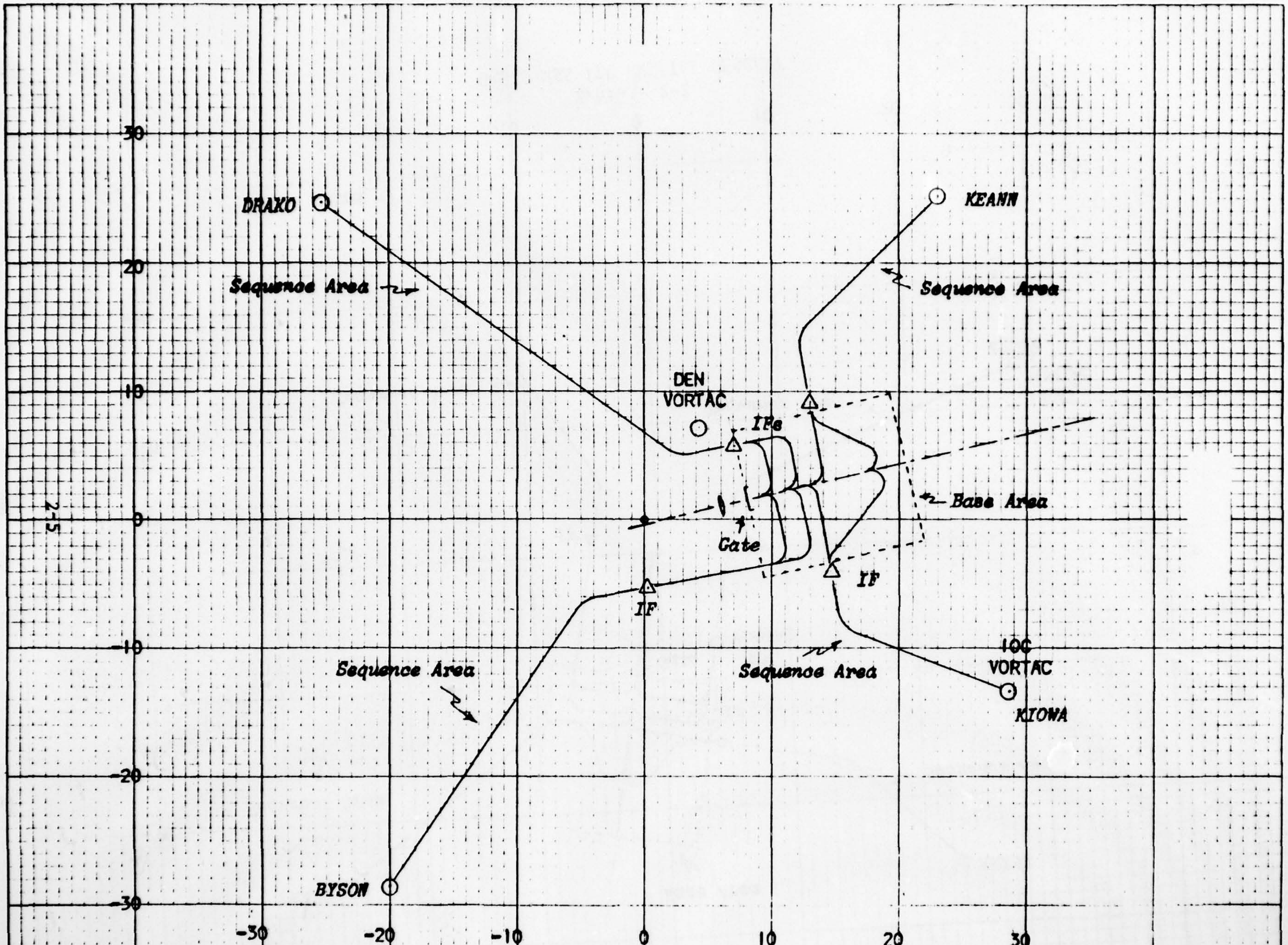


Exhibit 2-1

BASIC M&S 26L PROFILE DESCENT

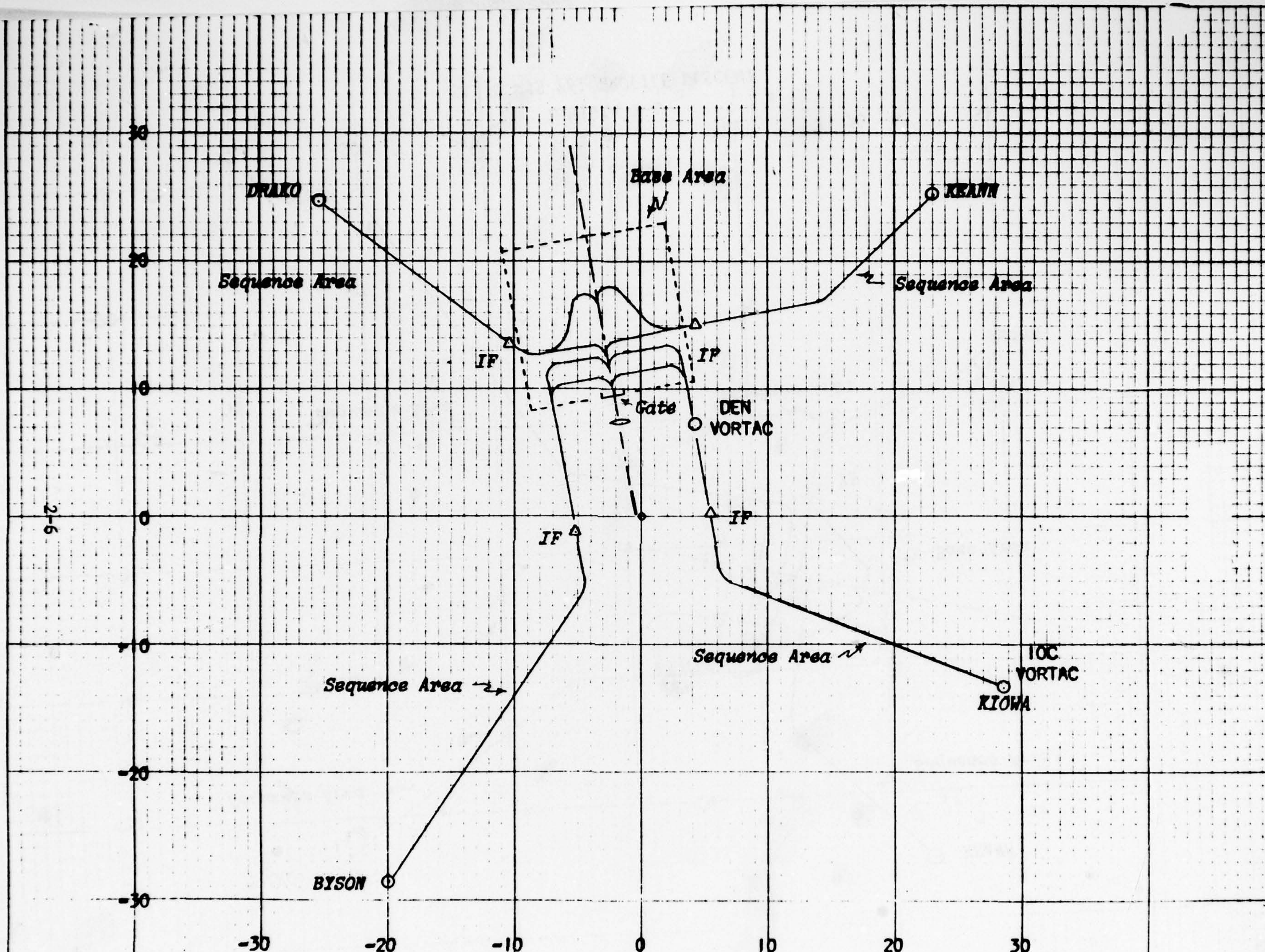


Exhibit 2-2
BASIC M&S 17R PROFILE DESCENT

The fundamental processes of the system are to (1) determine the landing sequence, (2) determine schedules that are realizable and will provide the minimum required spacing on final approach, and (3) determine what and when control actions (within the constraints of the geometry and procedures) should be taken to achieve the schedule. The control actions are displayed to the controller as suggested headings and speed changes. The word "suggested" is used here since the M&S determinations are based solely on the spacing of consecutive arrivals after the preceding aircraft crosses its final approach gate. The notion is that prior to that point, the controller will be able to maintain separation between flights without adversely affecting the time of delivery at the gate (e.g., by the application of vertical separation). (Note: Suggested altitude assignments are also displayed by the M&S program. These, however, are based on normal altitude assignments for the approach procedure in use and not on providing vertical separation between flights. They are intended only to serve as a reminder of when it is time for the flight to descend in order to make good the next altitude called for in the procedure.)

The sequence and schedules are initially determined well before the time aircraft are estimated to arrive at the terminal feeder fix. The purpose of this early determination is to ascertain if the delay that will have to be absorbed exceeds that which can readily be absorbed within the control geometry limits. If this is the case, the excess delay needs to be absorbed prior to the aircraft's departure from the feeder fix. The design incorporates two mechanisms related to absorbing the excess delay. If the excess delay is evident well in advance of the aircraft's entry into the terminal area, a PTDFF (proposed time to depart the feeder fix) message is formulated for automatic transmission to the enroute system; the notion being that the enroute system may be able to absorb the delay prior to the aircraft's arrival at the feeder fix. Otherwise, the aircraft is expected to hold at the feeder fix. The necessity to hold is indicated to the controller along with the expected time to depart the feeder fix. (Note: During the course of the basic M&S development effort, a form of enroute metering was introduced in the field. The objective of this enroute metering is to assure that aircraft will not be required to hold in the terminal area at high activity locations. As a result, it has been assumed that delays exceeding

that which can be absorbed in the terminal control geometry will not be experienced and the metering function of M&S (i.e., the PTDFF and Hold features) will not be needed. Whether this is a valid assumption for field operations has not been verified. However, with the traffic scenarios used in the tests covered by this report, it was not unusual for the amount of delay necessary to meet spacing requirements to exceed the normal controllability afforded in the sequence and base areas.)

The initial landing sequence is determined by comparison of the estimated times at the runway of each contending aircraft assuming flight is conducted over a nominal path from the feeder fix to the runway with no delay. A first-come/first-served principal is then applied. This initial sequence may change as a result of new aircraft entering the system or changes in estimated time of arrival at the feeder fix. As aircraft progress through the system, the sequence may also be changed as a result of approach path priority, unattainable schedule, or a controller request via keyboard entry. Approach path priority is an attempt to avoid the development of problems in meeting schedules by assigning a higher priority value to approach paths having the least favorable controllability. Schedule priority is an attempt to resolve the problem of an aircraft having more delay to absorb than can be absorbed within the remaining controllability of its particular geometry. Whether these priorities actually result in a re-sequencing action depends on the impact of the resequencing on the other aircraft. The keyboard request is to provide the controller a means of giving priority to a designated aircraft (e.g., one experiencing an in-flight emergency). A resequence results from the controller request irrespective of impact on the other flight.

The scheduled landing time is the later of the estimated earliest time the aircraft could reach the runway with no delay or the preceding aircraft's scheduled time at the runway plus the minimum landing time interval. The minimum landing time interval is the greater of the runway occupancy time of the preceding aircraft or a computed interval intended to meet spacing requirements on the final approach. In general, the computed interval is based on an estimate of the point on final approach where the minimum separation would occur and the resultant time interval at the runway to provide the appropriate separation at this point. The final value

of the computed interval represents the estimated minimum interval to satisfy spacing requirements plus deviation and probability factors intended to account for potential errors in gate delivery and time to fly assumptions.

When the scheduled time at the runway has been determined, scheduled times for the key control points (e.g., gate, IF and FF) are established. As aircraft proceed through the system, their updated estimated times of arrival at these control points is compared to the scheduled times. The difference is the basis for determining what, if any, control actions are necessary to achieve the schedule or if schedule adjustments (forward or backward slip) is appropriate.

3. OBJECTIVES AND KEY PERFORMANCE MEASURES

3.1 General

There are numerous measures that relate to system performance; however, many of the measures (e.g., tracking accuracy, wind estimation accuracy, etc.) are most useful in diagnosing the reasons for end results rather than in determining end results. The objective of Sterling Systems efforts was to determine overall performance of the terminal radar control system when operated with the basic metering and spacing package in contrast to the system's performance when operating without it. Accordingly, the measures considered most relevant to this objective are those which are indicative of end results that relate most directly to the terminal facility's mission, viz., the safe and expeditious movement of air traffic. The general approach adopted was, therefore, to concentrate on measures relevant to potential safe landing rates and potential excessive delays and to evaluate the performance of the control system against optimum performance when operated both with and without M&S automation. It should be noted that this approach assumes the various modules and features of the system have previously been tested to verify that they perform individually and together in accordance with the design intent, i.e., the key measures described in this section are oriented to determining end results and not towards isolating causes.

As previously noted, the measures considered most indicative of end results are the potential safe landing rate and potential excessive delay. These measures, however, draw heavily on the values derived in determining another measure, viz., Landing Time Interval Error. Discussions of these measures and their derivations are contained in the paragraphs that follow.

3.2 Landing Time Interval (LTI) Error

The standard deviation of the LTI error is an indication of the consistency of a system in achieving an interval whose relationship to the desired interval is represented by the mean error. A small standard deviation indicates a high degree of consistency and a large standard deviation indicates a low degree of consistency.

The mean LTI error, when coupled with the standard deviation, is useful in determining what adjustment may be necessary to assure that the system, as it performs, provides the minimum spacing consistent with its capabilities. For example, if a system exhibits a large, positive mean deviation from the desired interval (e.g., 45 seconds) but has a small standard deviation of error (e.g., 5 seconds), it would suggest that the criteria used by the system to determine intervals could be reduced by the equivalent of 35 seconds (2SD - Mean Error). If, on the other hand, the error was negative (e.g., -45 seconds) and the SD was 5 seconds, it would suggest the criteria be increased by the equivalent of 55 seconds (again, 2SD - Mean Error).

The derivation of LTI error obviously requires that the actual landing time interval be compared against some other value to determine the difference. There are at least two schools of thought on what the other interval should represent. One view is that the value should be the one used by the system in determining what it is attempting to achieve. In this case the mean and standard deviation of LTI error are measures of how well the system is capable of meeting its own goal. It is certainly a useful measure in determining whether design changes to improve controllability may be required but, it does not necessarily indicate the capability of the system to achieve operationally desired end results. Further, if comparisons are to be made of system performance with and without M&S, a methodology is not immediately evident for determining the appropriate target values when the M&S functions are being performed manually.

The other view, which is the one adopted by Sterling Systems for application in this analysis effort, is that the value used to determine LTI error should represent the best that could have occurred given the actual landing sequence, the actual aircraft performance as reflected by their track histories and the restraints imposed by final approach spacing minima, gap requests and runway occupancy times. This value is termed OLTI (Optimum LTI) in the discussions that follow.

Definitions of the various values pertinent to determining the LTI error and the methods by which they are determined are set forth below. In those cases where it is necessary to identify the particular aircraft of a given pair, the subscript p is used to denote the preceding aircraft and the subscript n is used to denote the next (following) aircraft.

ATAR (Actual Time at Runway Threshold) is the time a landing aircraft crosses the threshold of its landing runway on final approach.

ALTI (Actual Landing Time Interval) is the elapsed time from the passage of an arriving aircraft over the runway threshold until the passage of the next arriving aircraft over the threshold of the same runway.

$$ALTI = ATAR_n - ATAR_p$$

LTI Error (Landing Time Interval Error) is the plus or minus difference, in seconds, between the ALTI and the OLTI. A negative value indicates the ALTI was less than the required minimum.

$$LTI\ Error = ALTI - OLTI$$

OLTI (Optimum Landing Time Interval) represents the best landing interval that could have occurred with the landing sequence used, the actual aircraft performance as reflected by the track history data and the restraints imposed by final approach spacing minima, gap requests and runway occupancy times.

OLTI = The greater of the following:

- ROTC (Runway Occupancy Time Constraint)
- FSTC (Final Approach Spacing Time Constraint)
- GPTC (Gap Time Constraint)
- NDTC (No Delay Time Constraint)

ROTC (Runway Occupancy Time Constraint) is the elapsed time from the passage of the preceding aircraft over the runway threshold until that aircraft is clear of the runway.

ROTC = Measured runway occupancy time of $aircraft_p$ (if measured data is available, e.g., as a special measure taken during the course of testing in the field), or,

Pre-specified runway occupancy times for the particular type of aircraft, runway in use and field conditions assumed during tests.

Note: The runway occupancy times assumed during the tests covered by this report were $\leq$ 50 seconds which never became the constraining factor in any of the intervals.

FSTC (Final Approach Spacing Time Constraint) is the landing time interval that would ensue if, at some point between the time the preceding aircraft passes its gate and the time it crosses the runway threshold, the spacing between it and the following aircraft reaches (but does not go below) the appropriate final approach spacing minimum.

The appropriate final approach spacing minimum is the greater of the minimum spacing dictated by the weight class pairing (i.e., 3, 4, 5 or 6 miles) or by a specified minimum separation value. In manual operations, the latter value is conveyed to the controllers by the supervisor. In automated operations, it is additionally conveyed to the computer via a keyboard entry.

Determination of the FSTC value for a particular interval requires examination of the track history data of both aircraft involved in the interval to determine the time and position of $aircraft_p$ (while $aircraft_p$ is between the gate and the runway threshold) when the spacing between $aircraft_p$ and $aircraft_n$ reaches its minimum. A first approximation of the FSTC value is found as follows:

$$FSTC = (ATAR_n - ATAR_p) - (TMRS_n - TPMS_p)$$

where:

$TMRS_n$ = The time $aircraft_n$ first reaches that point where its spacing from PMS_p is equal to the required spacing value.

PMS_p = The position of $aircraft_p$ at the point of minimum spacing between $aircraft_p$ and $aircraft_n$ while $aircraft_p$ is between the gate and the runway.

$TPMS_p$ = The time $aircraft_p$ is at PMS_p.

This approximation assumes that the position of $aircraft_p$ at the point of minimum spacing would remain the same if $aircraft_n$ is move forward (or back) in time by ($TMRS_n$ - $TPMS_p$) so that the minimum spacing value is reached when $aircraft_p$ is at PMS_p.

If the ground speed of $aircraft_p$ is always less than the ground speed of $aircraft_n$, then the aircraft will always be converging while $aircraft_p$ flies from the gate to the runway. PMS_p will then be at the runway threshold and, if the relative velocity of the two aircraft continues to be convergent when $aircraft_n$ is shifted in time, PMS_p will remain at the runway threshold and the first approximation value will be the correct value. Similarly, if the ground speed of $aircraft_p$ is always greater than the velocity of $aircraft_n$, then the aircraft will always be diverging and PMS_p will be located at the gate. If the relative velocity of the two aircraft continues to be divergent when $aircraft_n$ is shifted in time, PMS_p will remain at the gate and the first approximation value will again be the correct value.

In many cases, however, the relative velocities of the two aircraft will not follow this pattern when $aircraft_n$ is shifted in time. Typically, when $aircraft_p$ is at the gate, $aircraft_n$ is still slowing down from a ground speed greater than that of the lead aircraft. This produces a situation which is initially one of convergence but which may change to one of non-convergence or divergence when the ground speed of $aircraft_n$ reduces to a value equal to or less than that of the lead aircraft. Under these circumstances, when $aircraft_n$ is shifted in time, the location of PMS_p may also shift making it necessary to find the new location of PMS_p and determine whether the minimum separation value is achieved at that point. If not, $aircraft_n$ is again shifted in time and the process is repeated until the correct PMS_p is found.

<u>GPTC</u> *(Gap Time Constraint)* is the time taken by $aircraft_n$ to reach the runway from a distance that is equal in value to the distance of the specified gap.

In manual operations, the gap would normally be requested by the local controller in the control tower cab. In automated operations it is

additionally conveyed to the computer via keyboard entry indicating the value of the gap (in miles) and the aircraft behind which the gap is to be provided.

$$GPTC = ATAR_n - TSGD_n$$

where:

$TSGD_n$ = The time $aircraft_n$ was at the specified gap distance from the runway threshold.

Note: The gap request feature was not used during the tests covered by this report.

NDTC (No Delay Time Constraint) is the shortest landing interval that could have been made good by $aircraft_n$.

$$NDTC = ETAR_n - ATAR_p$$

where:

$ETAR_n$ = The earliest time $aircraft_n$ could have arrived at the runway with no delay.

Note: The purpose of NDTC is to avoid the assessment of LTI error for intervals that could not have been made good due to gaps in the demand, thus, it is highly desirable that $ETAR_n$ be accurate. $ETAR_n$, however, is normally determined by adding the minimum time for $aircraft_n$ to fly from the feeder fix to the runway ($MTTF_n$) to the time $aircraft_n$ passed the feeder fix. Unfortunately, MTTF is not a very precise measure, i.e., given the same performance category aircraft, from the same fix, at the same initial altitude, going to the same runway, with the same wind conditions, variations in the time to fly occur even when no intentional actions to cause delay have been taken. This is attributed primarily to the fact that there are humans in the control loop (controllers and simulator pilots) and their response times are not precisely the same from time to time. Also, it was noted that the minimum path and latest point of speed reduction used by M&S were more constraining than those sometimes used by the controllers when operating without M&S. Consequently, the MTTFs used in this analysis, were derived from two sets of runs (one without M&S

and one with M&S) made for this particular purpose. The MTTF values derived from the special MTTF runs made without M&S were used in determining the ETAR values for the test runs made without M&S. The MTTF values derived from the special MTTF runs made with M&S were used in determining the ETAR values for the test runs made with M&S. Additionally, because of the imprecision in the measurement, the NDTC was used as a filter, i.e., if OLTI was equal to NDTC, the interval was excluded from the run statistics and histograms.

Since this procedure differs from the procedure employed in Sterling Systems previous performance assessment, it prompts the question of whether the outcome of the previous assessment would have been different had these procedures been applied. An investigation of this question revealed that although there would have been some small differences in the absolute values of the key measures, there would have been no substantive differences and the conclusions would have been the same.

3.3 Potential Safe Landing Rate

The potential safe landing rate is a function of the delivery performance exhibited by the system and the traffic mix encountered. It is intended to represent the equivalent landing rate of the system if the system were adjusted to assure with some high degree of probability (e.g., 97 or 98%) that minimum spacing requirements would be satisfied and given a constant demand with a traffic mix representing a composite of the mix encountered in all runs in the test series.

Since delivery performance is indicated by the standard deviation of LTI errors, the potential safe landing rate is derived as follows:

$$\text{Potential Safe Landing Rate} = \frac{3600}{\text{Average Adjusted OLTI} + \text{Spacing Assurance Buffer}}$$

where:

Adjusted OLTI is the greater of ROTC, FSTC or GPTC (i.e., NDTC is excluded since its purpose in the OLTI determination is only to avoid assessment of unavoidable gaps as LTI errors and the intent here is to assume constant demand).

Average Adjusted OLTI is the average of the Adjusted OLTI of all test runs. (Note: Average Adjusted $OLTI_{(n)}$ is the Average Adjusted OLTI for the particular test run. Since it can vary from run to run as a function of traffic mix, final landing sequence and actual ground speed on the final approach, the average of the Adjusted OLTI of all runs is considered the preferable value in determining the potential safe landing rate for comparison purposes.)

Spacing Assurance Buffer is equal to:

2 standard deviations of LTI error if the mean LTI error is a positive value, or

2 standard deviations of LTI error + |Mean LTI error| if the mean LTI error is a negative value.

3.4 Potential Excessive Delay

Actual delay is the difference between the actual time of arrival at the runway and the earliest time of arrival that could have been made good with no delay. This figure, however, has little meaning in assessing system performance since the control mechanism is one that requires the application of delay to achieve the required spacing between flights. Thus, even a system working to perfection requires the imposition of delay unless demand is so light that essentially no control is required.

Excessive delay is the difference between the actual delay and the unavoidable delay required to meet spacing requirements. The excessive delay value is indicated by the LTI error (i.e., a positive error indicates the amount that delay exceeded the minimum required and a negative error indicates that more delay was needed to have provided the minimum required spacing).

The potential excessive delay is a companion measure to potential safe landing rate and indicates the potential excessive delay, per aircraft, for the system if operated to provide the potential safe landing rate. The potential excessive delay is simply equal to the spacing assurance buffer.

3.5 Minimum Experienced vs. Minimum Required Spacing

Minimum Experienced vs. Minimum Required Spacing is a measure of the +/- difference in distance batween the minimum spacing dictated by the weight classes of the aircraft and the minimum spacing that occurred between the time the preceding aircraft passed its gate and the time it reached the runway threshold. Determination of this value requires examination of the track history data of both aircraft involved in the interval to find the minimum spacing experienced. Having found this value, the +/- difference is simply,

Minimum Spacing Experienced - Minimum Spacing Required.

4. SYSTEM PERFORMANCE TESTS

4.1 General

The performance tests covered by this report consisted of a series of dynamic simulations of terminal arrival operations at Denver's Stapleton International Airport. These tests were made utilizing the test facilities at NAFEC to simulate the Denver terminal area operational environment. ARTS III equipment in the Terminal Automation Test Facility (TATF) was used to perform the data processing and display functions while the Digital Simulation Facility (DSF) was used to simulate the air situation and the data acquisition system, i.e., compute aircraft movement and generate scan-to-scan radar/beacon target reports.

Two different traffic samples were used. These were selected from the samples available in the TATF library and had been prepared by NAFEC personnel based on data recorded at Denver during live operations. When applied to the two different runways, and with some variations in the aircraft's times of arrival at the feeder fixes, the two traffic samples actually constituted four different traffic scenarios. Detailed information concerning the make up of these scenarios is presented in Appendix A.

In the June 1978 tests, each of the scenarios was run once without M&S automation to provide a basis for comparison with runs made with M&S automation assistance added. The runs without M&S automation were made utilizing Denver controllers. As a practical matter, these tests were not repeated in the December/January test series. Instead, the data collected in the earlier tests was used in determining system performance without Basic M&S automation.

Test data provided by the FAA from the December/January test series were from six test runs made with M&S. Four of these runs (each with a different traffic scenario) were made with the traffic unmetered as was the case in the earlier test runs without M&S (i.e., no control actions were taken to absorb delay prior to the aircraft's passing the feeder fix inbound). The remaining two runs were made with the 41 aircraft sample to each of the two different runways (i.e., Scenarios A2641 & D1741).

In these runs, simulation of the metering function was also undertaken to gain some initial insight of its impact on overall performance. The method of simulation consisted of test personnel monitoring a display of the aircraft's estimated times of arrival at the feeder fix. When a proposed time to depart the feeder fix (PTDFF) was displayed for one of these aircraft by M&S (indicating delay should be absorbed before passing the feeder fix inbound), efforts were made to delay the target generator's start of the aircraft into the problem by an amount equal to the difference between the PTDFF and the ETA at the feeder fix. This entailed having the DSF simulator pilot disengage automatic start up of the target and initiate manual start up on command from test personnel in the TATF.

A list of the test runs analyzed for this report along with the date the run was made and the scenario used is provided in Table 4-1.

4.2 M&S Program Changes

The principal changes made in the M&S software prior to the December/January test series were as follow:

- The landing time interval (LTI) computation program was redesigned to provide a better estimate of the point where minimum separation would occur and the resultant time interval required at the runway to provide the appropriate separation at this point.
- The speed monitoring and time-to-fly computations were modified to provide earlier detection of aircraft deceleration and to recognize deceleration during turns.
- The M&S program was integrated with the Conflict Alert (AØ.15) version of the ARTS III operational program.

In addition to the above, the wind derivation and update modules had been redesigned to provide for deriving estimates of wind components by monitoring the performance of aircraft navigating with reference to VOR radials in profile descent geometries as well as those flying with reference to

Table 4-1

TEST RUNS INCLUDED IN THE ANALYSES

Date	Run No.	Scenario	NAFEC ID	Remarks
6-7-78	1	A2638	1	Without M&S
12-20-78	2C	"	5K	With M&S Unmetered
6-12-78	3	A1738	3	Without M&S
1-12-79	4C	"	2R	With M&S Unmetered
6-9-78	5	A2641	5	Without M&S
12-20-78	6C	"	11K	With M&S Unmetered
12-12-78	6D	"	7E	With M&S Metered
6-12-78	7	D1741	7	Without M&S
12-15-78	8C	"	12G	With M&S Unmetered
12-8-78	8D	"	8D	With M&S Metered

Runs made without M&S are odd numbered.

Runs made with M&S are even numbered.

The suffix "C" with M&S run numbers indicates the run was unmetered.

The suffix "D" with M&S run numbers indicates the metering function was simulated during the run.

The first two numerics in the Scenario indicate the runway to which the run was made; the last two numerics indicate the number of aircraft in the sample.

assigned headings. However, since these design changes had not been completely checked out and it was desired to separate the question of wind estimation accuracy from the other aspects of M&S performance, the December/January series of test runs were made with the wind updates disabled and the wind values input to M&S at the start of each run were the same as those used in the DSF target generator (i.e., the true winds).

4.3 Ground Rules and Assumed Conditions

The basic ground rules and assumed conditions governing the tests were as follow:

Ground Rules

- During the runs without M&S, controllers would use control procedures which are commonly practiced at Denver. (As previously noted, Denver controllers were used for these runs.)
- During the runs with M&S, the heading and speed commands, as issued by M&S, would be used (i.e., the controllers were not to modify or anticipate the control actions).
- Missed approaches would not be given since this would negate use of the preceding and ensuing intervals in determining control error statistics.

Assumed Conditions

- Instrument flight conditions in which only the primary instrument runway could be used (i.e., visual approaches to the parallel runway could not be made).
- Good braking action with runway occupancy times equal to or less than 50 seconds.
- Surveillance errors prior to quantizing:

	Mean	Standard Deviation
Azimuth	0	0.23°
Range	0	0.02 NM

- Winds aloft as indicated in Table 4-2.

Table 4-2

WINDS ALOFT

Altitude	Runs to Runway 17R		Runs to Runway 26L	
	Dir.	*Vel.*	*Dir.*	*Vel.*
6,000	*200°*	*14 Knots*	*300°*	*14 Knots*
7,000	"	*18 "*	"	*18 "*
8,000	"	*22 "*	"	*22 "*
9,000	"	*26 "*	"	*26 "*
10,000	"	*30 "*	"	*30 "*
11,000	"	*34 "*	"	*34 "*
12,000	"	*38 "*	"	*38 "*
13,000	"	*41 "*	"	*41 "*
14,000	"	*44 "*	"	*44 "*
15,000	"	*47 "*	"	*47 "*
16,000	"	*50 "*	"	*50 "*
17,000	"	*53 "*	"	*53 "*
18,000	"	*55 "*	"	*55 "*
19,000 & above	"	*55 "*	"	*55 "*

4.4 Test Anomalies

4.4.1 June Test Series

While carrying out post-test analyses of data during the earlier M&S assessment effort, several anomalies/imperfections in the simulation were noted. Some of these could be expected to more adversely affect the performance of the system when operated with M&S automation than when operated without it. In brief, the items noted were as follow:

a. Scan-to-scan irregularities in the position of target reports appeared greater than those observed with operational systems in the field. This apparently was the combined result of two factors -- (1) the surveillance error model used in the simulation employs a random number generator to determine the magnitude of range and azimuth error to be induced with each target report whereas the examination of field data suggests the errors may not be experienced in a completely random fashion, and, (2) the range quantizing practice in use in the DSF was to round to one sixteenth and then truncate to one eighth mile whereas, in the field system, range is truncated to one sixteenth mile. Since the controller has another source of information concerning current speed and heading (viz. the pilot or, in this case, the simulator pilot), the effect of these irregularities on performance when operating without M&S should be inconsequential. On the other hand, M&S is reliant on the tracking system for current speed and heading data and extensive jitter in positional data adversely affects tracking performance. Thus, it is highly probable that the irregularities noted would have an adverse impact on the performance exhibited by the system when operated with M&S.

b. The demand imposed by the scenarios was expected to represent a flow of traffic that had been metered by the enroute system. However, the demand imposed by some of the scenarios was substantially greater over significant periods of time than what

might be considered a reasonable capacity for a single runway. This resulted in aircraft entering the base area with extensive delay yet to be absorbed which necessitated extending the downwind leg further and further as the delay to be absorbed built up. In the runs without M&S automation, the controllers were more able to cope with this situation by applying current field procedures in which pilots are requested to increase their speed when a gap between their aircraft and the preceding aircraft is starting to develop. In contrast, guidelines governing the M&S development effort were that speed increases would not be allowed, thus the basic M&S automation package does not have this mechanism for adjusting intervals when aircraft are committed to a long final approach and all other control mechanisms have been exhausted. Accordingly, it is reasonable to expect that performance of the system when operated with M&S would be more adversely affected by these conditions.

c. In many (but not all) instances there was an interruption in the descent of the simulated aircraft coincident with its initiation of a response to an early slowdown to 180 knots. The period of time that the flight remained level before resuming descent ranged from 14 seconds to 6 minutes and 27 seconds. It is believed that the cause is related to the manner in which the speed change is entered into the target generation program at a time when the target is executing a profile descent under program control. The result is that the target, though slowing to 180 knots IAS, is operating at a higher than expected altitude and thus a higher TAS which, in turn, results in more delay remaining to be absorbed in the base area. The adverse impact on performance would therefore be similar to that described in subparagraph b.

d. There were several geometry discrepancies between the DSF and M&S data bases. The end effect of one of these discrepancies was that aircraft were operating slightly longer at a lower speed on the final approach to Runway 17 than would have otherwise

been the case. However, since the same situation existed in all test runs to Runway 17, there is no reason to believe that any possible adverse effects would have been any different for the runs made with or without M&S.

4.4.2 December/January Test Series

Since the results of the December/January test series with M&S were to be compared with the runs made without M&S in June, there was, with one exception, no action taken to correct the previously noted anomalies prior to these tests. The one exception was that the quantizing practice used in the DSF was changed to truncate range to one sixteenth mile granularity as is the case in field systems. The assumed surveillance system errors prior to quantizing as well as the manner in which they are induced were not changed, nor were the other anomalies even though it was reasoned their impact on system performance would be more adverse when the system is operating with M&S.

5. TEST DATA

The test data available for analysis consisted of computer printouts of data automatically recorded during each test run in the Digital Simulation Facility (DSF) and the Terminal Automation Test Facility (TATF). Additionally, notes made by the NAFEC Test Director during the course of a run indicated instances where errors in the way the run was conducted were noted by the controllers (e.g., simulator pilot made an entry causing a 260° left turn instead of a left turn to a heading of 260°).

The DSF data consisted of summary data and aircraft time-position history data. At the request of the authors, the aircraft time-position histories were sorted by individual aircraft and, through commendable efforts on the part of the DSF data reduction programmer, were provided in a special format to facilitate application of the measures described in Section 3. These data, which were the principal source in determining the values contained in the tabulations of each test run as presented in Appendix B and C, included the time, true position (i.e., before sensor noise and truncation effects), altitude, ground speed and ground track of the aircraft at times corresponding to the time the target report for the particular aircraft was sent from the DSF to the TATF. Thus, for a particular aircraft, the time between data points was approximately four seconds. The data also include the flight path distance remaining to reach the runway threshold which was derived by subtracting the distance flown up to the time of the entry (a normal measure maintained by the DSF target generator extraction program) from the total distance flown to reach the runway threshold. This aided immeasurably in reducing the efforts necessary to determine the FSTC value.

The TATF data were extracted using the general purpose Data Recording and Timing (DRAT) program employed with the basic M&S software package. These data were reduced using the general purpose Data Reduction and Analysis of Tape INput (DRAIN) program associated with the DRAT extractor. The DRAIN data consisted of summary data and a detailed chronological listing of M&S data including track velocity and bearing (ground track), XY of target reported position and reported altitude as well as various entries regarding

gross scheduling, tentative scheduling, schedule changes, resequencing, controllability, status, etc. Sorting of these data by individual aircraft was not provided.

PTDFF (Proposed Time to Depart the Feeder Fix) data for the metered runs was provided by UNIVAC.

6. TEST RESULTS

6.1 General

Detailed lists of the key measurement values derived from each of the test runs are contained in Appendix B. Final approach spacing differences between the minimum required and the minimum experienced during each run are provided in Appendix C. This section presents statistical summaries of these measures in the form of tables, graphs and histograms.

The summaries have been organized to facilitate comparison of the results of runs made with M&S against the results of runs made without M&S. Odd numbers identify runs made without M&S; even numbers identify runs made with M&S. The letter suffix "C" with an M&S run number indicates traffic inbound to the feeder fixes was unmetered while the letter suffix "D" indicates metering was applied.

Two sets of results, identified as (-1) and (-2), are presented for each of the metered runs. The differences result from two different methods of determining the ETAR value, which, in turn, results in differences in the NDTC values. Since the NDTC value is used as a filter (i.e., when OLTI = NDTC, the interval is excluded from the run statistics), differences in the NDTC value can result in differences in the individual intervals excluded.

For unmetered runs, ETAR is defined as TAFF (time at feeder fix) + MTTF (minimum time to fly from the feeder fix to the runway). For metered runs, however, this method does not account for the possibility of excessive delay being imposed by the control system in its application of the metering action.

In the (-1) results, the method used to determine the ETAR for aircraft where a PTDFF (proposed time to depart the feeder fix) had been generated by M&S was ETAR = No Delay TAFF + MTTF where No Delay TAFF is the time the aircraft could have arrived at the feeder fix if no delay had been imposed. The (-1) values thus indicate the end results of the metered runs without distinction between the metering and the spacing aspects.

In the (-2) results, the method used to determine the ETAR was the same as described for unmetered runs thus the (-2) values are indicative of the performance achieved by the spacing function when traffic is metered to absorb some of the required delay prior to reaching the feeder fix.

Further discussion of imperfections in the metering process (as simulated) that contributed to the differences in the (-1) and (-2) results is contained in paragraph 6.3.

6.2 Individual and Combined Test Run Results.

6.2.1 Key Performance Measures

The key performance measures derived from each test run are summarized in Table 6-1.

The most critical measure of performance is the standard deviation of LTI error. This is because a large dispersion in LTI error indicates that arriving aircraft must be given large LTIs in order to minimize spacing violations. However, with a small dispersion in LTI error, compensation can be made for any value of mean error and smaller LTIs may be scheduled.

The standard deviation of LTI error for each of the test runs is presented graphically in Exhibit 6-1. It may be noted that the standard deviation of LTI error for all unmetered runs with M&S is less than that of the corresponding run without M&S and, with exception of the Run 5/6C comparison, the reduction is substantial (i.e., on the order of 50%). It may also be noted that the standard deviation of LTI error for the two metered runs where imperfections in the metering process were isolated from the results (i.e., the (-2) values), are on the order of 20% less than the corresponding unmetered runs. This tends to support the notion that the spacing function of M&S will perform better when some of the required delay (when required delay is extensive) is absorbed before aircraft reach the feeder fix.

The relatively poor performance shown for the (-1) method of assessing the metered runs is caused by 8 instances (2 in Run 6D and 6 in Run 8D) where the delay imposed by the metering process was greater than the

Table 6-1

INDIVIDUAL TEST RUN RESULTS - KEY PERFORMANCE MEASURES

Date	Test Run Number	Traffic Sample	Number of Intervals	LTI Error Mean	LTI Error S.D.	Av. ALTI	Av. OLTI	Average Adjusted OLTI $_{(n)}$	Average Adjusted OLTI Runs 1-3-5-7-2C-4C-6C-8C	Actual Landing Rate	Average Excessive Delay per Aircraft	Potential Safe Landing Rate	Potential Excessive Delay per Aircraft
6-07-78	[1]	A2638	32	14.22	16.42	100.88	86.66	86.66	90.61	35.69	14.22	29.16	32.84
12-20-78	2C	"	23	0.09	10.04	84.39	84.30	84.30	"	42.66	0.09	32.52	20.08
6-12-78	[3]	A1738	35	9.26	16.92	98.17	88.91	88.91	"	36.67	9.26	28.93	33.84
1-12-79	4C	"	35	8.49	8.49	96.40	87.91	87.91	"	37.34	8.49	33.46	16.98
6-09-78	[5]	A2641	30	7.57	13.68	99.70	92.13	92.13	"	36.11	7.57	30.52	27.36
12-20-78	6C	"	24	-0.83	12.42	89.83	90.67	90.67	"	40.07	-0.83	31.18	24.84
12-12-78	6D(-1)	"	27	2.93	17.91	98.67	95.74	95.74	"	36.49	2.93	28.47	35.82
	6D(-2)	"	25	-1.20	10.30	91.80	93.00	93.00	"	39.22	-1.20	32.37	20.50
6-12-78	[7]	D1741	31	0.71	17.91	97.55	96.84	96.84	"	36.90	0.71	28.47	35.82
12-15-78	8C	"	35	4.60	6.96	100.54	95.94	95.94	"	35.81	4.60	34.44	13.92
12-08-78	8D(-1)	"	36	10.47	18.72	109.67	99.19	99.19	"	32.83	10.47	28.11	37.44
	8D(-2)	"	30	3.20	5.41	101.77	98.57	98.57	"	35.38	3.20	35.49	10.82

[ ] Indicates Test Run made without Basic M&S Automation

Revised May 8, 1979

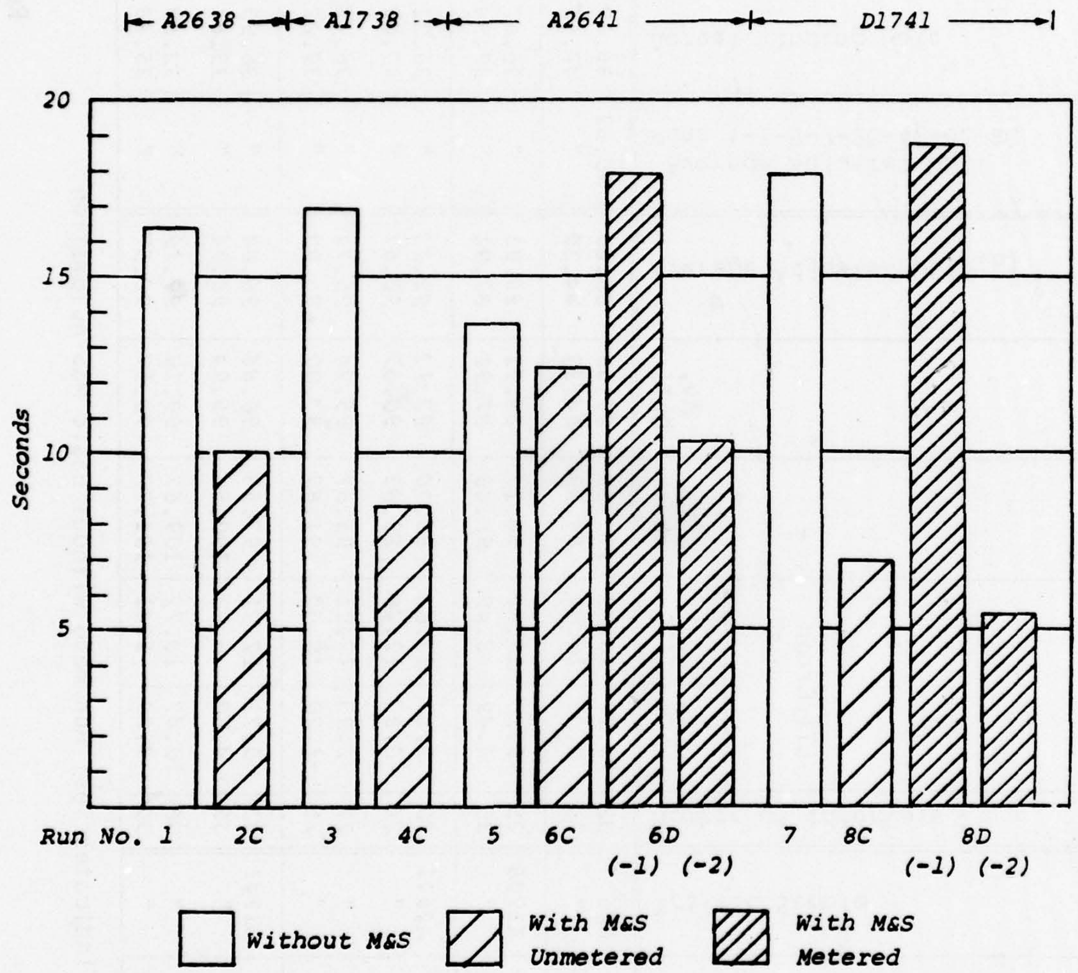


Exhibit 6-1

STANDARD DEVIATION OF LTI ERROR

delay required thus creating gaps that were assessed as positive LTI errors. This aspect of the metering process, as simulated, is explored further in paragraph 6.3.

The effect of a reduction in the standard deviation of LTI error is an increase in the potential safe landing rate. This is illustrated in Exhibit 6-2 where the potential safe landing rate for each test run is presented graphically.

Table 6-2 presents the resulting key performance measures when the measures from the runs without M&S are combined and the measures from the runs with M&S are combined. The data in this table indicates the potential safe landing rate exhibited by the unmetered runs with M&S is about 12% higher than that exhibited by the runs without M&S. Additionally, assuming imperfections encountered in the metering process are rectified, the (-2) entries for the metered runs suggest an increase in the potential safe landing rate of about 3% when the traffic is metered as opposed to when it is not.

It may also be noted from this table that the potential excessive delay per aircraft is about 14 seconds less for the unmetered runs with M&S than for the runs without M&S. It will be remembered that the potential excessive delay per aircraft is a companion measure of the potential safe landing rate and indicates the average expected difference between total delay and unavoidable delay required to meet spacing requirements if the system were operated to provide the potential safe landing rate.

Again assuming imperfections encountered in the metering process are rectified, the (-2) entries for the metered runs suggest a further reduction in the potential excessive delay per aircraft of about 3 seconds. What is perhaps even more important in this case, however, is that when the demand is high and extensive delay is required, most of the delay is absorbed while the aircraft is operating at a higher altitude and in a configuration more favorable to fuel conservation.

Histograms of the distribution of LTI errors for the combined runs are presented in Exhibits 6-3 and 6-4.

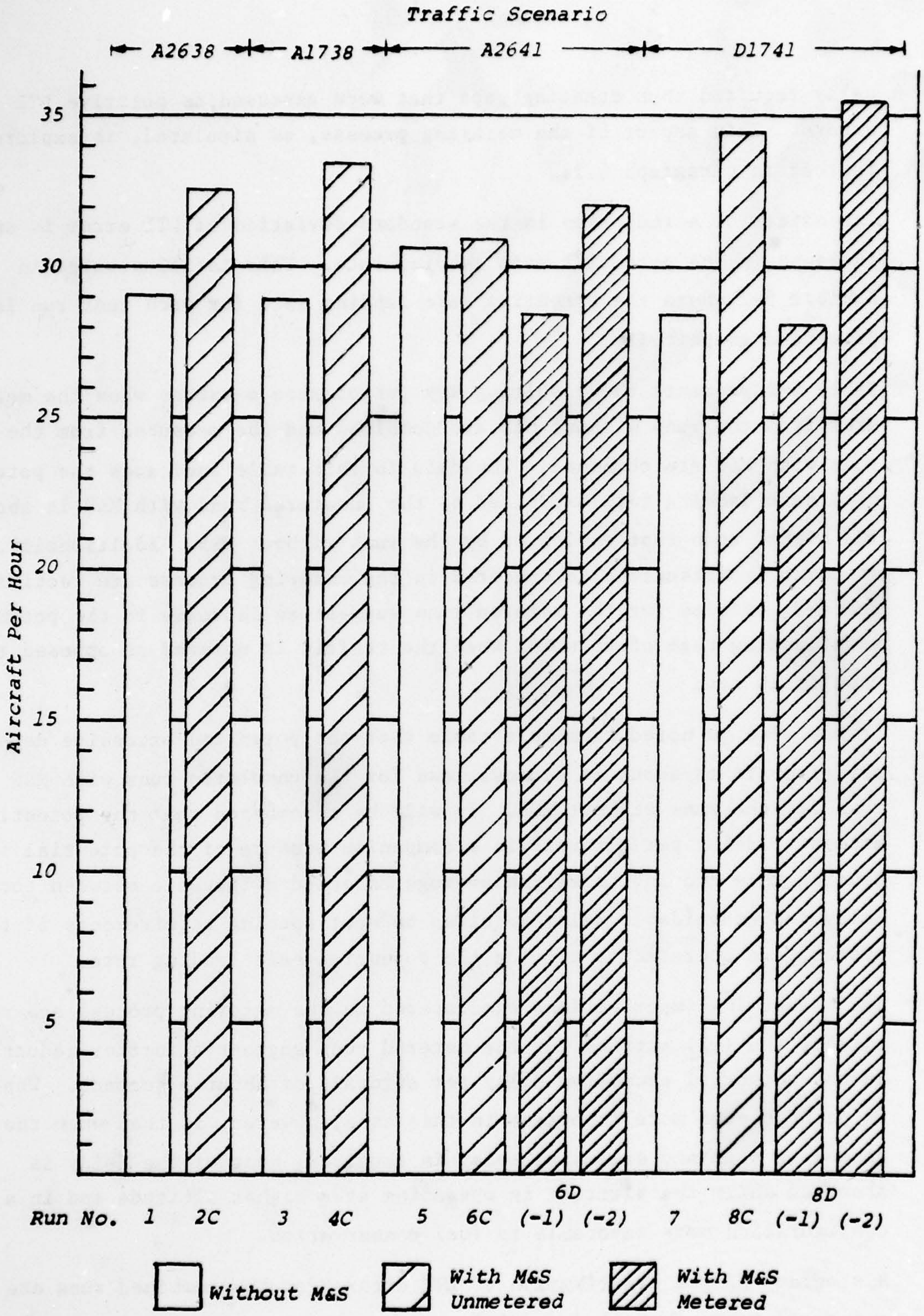


Exhibit 6-2

POTENTIAL SAFE LANDING RATES

Table 6-2

COMBINED TEST RUN RESULTS - KEY PERFORMANCE MEASURES

Combined Runs	Number of Intervals	LTI Error		Av. ALTI	Av. OLTI	Average Adjusted $OLTI_{(n)}$	Average Adjusted OLTI Runs 1-3-5-7-2C-4C-6C-8C	Actual Landing Rate	Average Excessive Delay per Aircraft	Potential Safe Landing Rate	Potential Excessive Delay per Aircraft
		Mean	S.D.								
1, 3, 5 & 7	128	8.03	17.04	99.06	91.02	91.02	90.61	36.34	8.03	28.87	34.08
2C, 4C, 6C & 8C	117	3.76	10.07	93.93	90.17	90.17	"	38.33	3.76	32.51	20.14
5 & 7	61	4.08	16.33	98.61	94.52	94.52	"	36.51	4.08	29.20	32.66
6C & 8C	59	2.39	9.93	96.18	93.80	93.80	"	37.43	2.39	32.59	19.86
6D(-1) & 8D(-1)	63	7.24	18.75	104.96	97.71	97.71	"	34.30	7.24	28.10	37.50
6D(-2) & 8D(-2)	55	1.20	8.31	97.24	96.04	96.04	"	37.02	1.20	33.57	16.62

RUNS 1, 3, 5 & 7

No. Intervals:		128
Range	:	-36/+55
Mean	:	8.03
Std. Dev.	:	17.04

RUNS 2C, 4C, 6C & 8C

No. Intervals:		117
Range	:	-26/+28
Mean	:	3.76
Std. Dev.	:	10.07

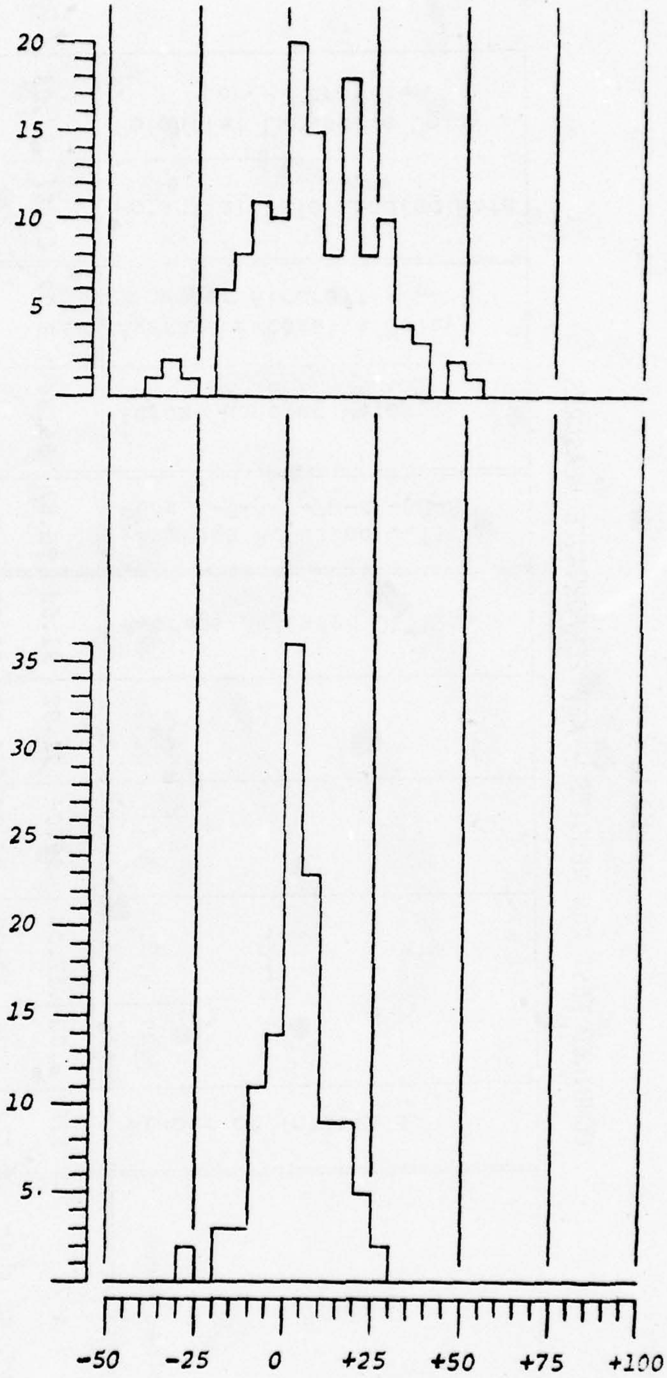


Exhibit 6-3

LTI ERROR DISTRIBUTION

RUNS 5 & 7

No. Intervals	:	61
Range	:	-36/+50
Mean	:	4.08
Std. Dev.	:	16.33

RUNS 6C & 8C

No. Intervals	:	59
Range	:	-26/+24
Mean	:	2.39
Std. Dev.	:	9.93

RUNS 6D(-1) & 8D(-1)

No. Intervals	:	63
Range	:	-23/+76
Mean	:	7.24
Std. Dev.	:	18.75

RUNS 6D(-2) & 8D(-2)

No. Intervals	:	55
Range	:	-23/+19
Mean	:	1.20
Std. Dev.	:	8.31

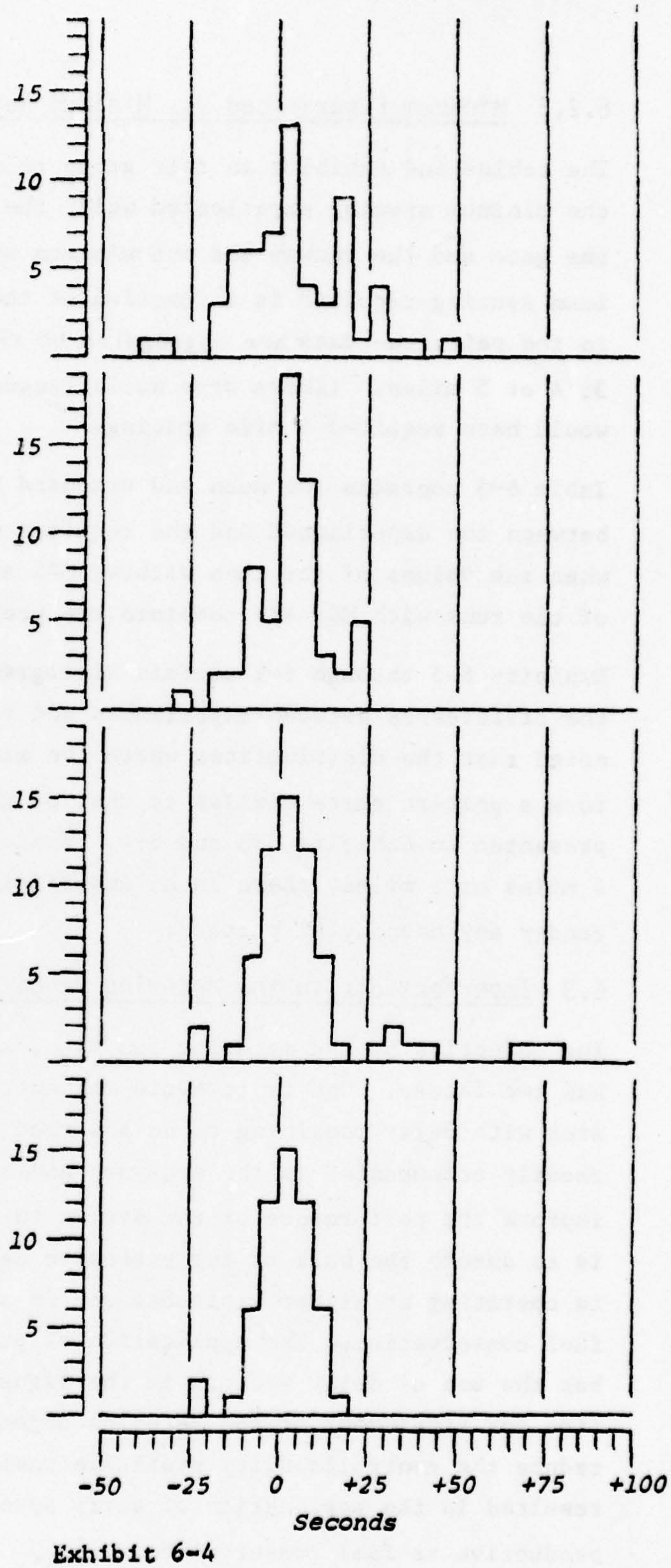


Exhibit 6-4

LTI ERROR DISTRIBUTION

6.2.2 Minimum Experienced vs. Minimum Required Spacing

The tables and exhibits in this group relate to the +/- difference between the minimum spacing experienced while the preceding aircraft was between the gate and the runway and the minimum spacing required. Since the minimum spacing required is a function of the weight classes of the aircraft in the pair, the data are segregated by the required spacing value, i.e., 3, 4 or 5 miles. (There were no instances of weight class pairings that would have required 6 mile spacing.)

Table 6-3 contains the mean and standard deviation of the differences between the experienced and the required minimum for each run. The results when the values of the runs without M&S are combined and when the values of the runs with M&S are combined are presented in Table 6-4.

Exhibits 6-5 through 6-9 contain histograms depicting the distribution of the differences between experienced and required spacing. It will be noted that the distributions where the minimum required spacing is 3 miles form a pattern quite similar to that of the distributions of LTI error presented in Exhibits 6-3 and 6-4. Where the minimum required spacing is 4 miles or 5 miles, there is an insufficient number of measurements to render any meaningful pattern.

6.3 Imperfections in the Metering Process

The objective of the metering function, as incorporated in the M&S design, has two facets. One is to avoid the entry of aircraft into the sequence area with delay remaining to be absorbed which exceeds that which can be readily accomodated in the sequence and base areas. Logically, this should improve the performance of the system in achieving desired LTIs. The other is to absorb the bulk of any extensive delay required while the aircraft is operating at higher altitudes and in a configuration more conducive to fuel conservation. The application of profile descent procedures which bar the use of delay vectors in the sequence area provide further motivation for attainment of the metering objective since the procedures (1) reduce the controllability available inside the feeder fixes and (2) have resulted in the application of early speed reductions which are counterproductive to fuel conservation.

Table 6-3

INDIVIDUAL TEST RUN RESULTS
EXPERIENCED VS. REQUIRED FINAL APPROACH SPACING

Run No.	Sample	Required = 3 Mi.			Required = 4 Mi.			Required = 5 Mi.		
		No.	Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.
[1]	A2638	29	0.67	0.57	1	-1.02	----	2	-0.22	0.10
2C	"	21	0.05	0.37	1	-0.47	----	1	-0.29	----
[3]	A1738	32	0.45	0.53	1	-1.44	----	2	-0.78	0.11
4C	"	32	0.33	0.35	1	0.30	----	2	0.34	0.44
[5]	A2641	25	0.40	0.53	2	-0.18	0.25	3	-0.29	0.51
6C	"	21	-0.03	0.43	1	-0.88	----	2	0.47	0.53
6D(-1)	"	22	0.15	0.67	2	0.66	0.90	3	-0.26	0.18
6D(-2)	"	21	0.03	0.42	1	-0.24	----	3	-0.26	0.18
[7]	D1741	26	0.10	0.66	2	-0.72	0.72	3	-0.12	0.28
8C	"	30	0.18	0.25	2	0.32	0.08	3	-0.04	0.10
8D(-1)	"	30	0.32	0.58	3	0.10	0.21	3	1.40	1.37
8D(-2)	"	26	0.13	0.19	3	0.10	0.21	1	-0.17	----

Table 6-4

COMBINED TEST RUN RESULTS

EXPERIENCED VS. REQUIRED FINAL APPROACH SPACING

Combined Runs	Required = 3 Mi.			Required = 4 Mi.			Required = 5 Mi.		
	No.	Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.
1, 3, 5 & 7	112	0.41	0.61	6	-0.71	0.63	10	-0.32	0.40
2C, 4C, 6C & 8C	104	0.16	0.37	5	-0.08	0.51	8	0.15	0.44
5 & 7	51	0.24	0.62	4	-0.45	0.60	6	-0.21	0.42
6C & 8C	51	0.09	0.35	3	-0.08	0.57	5	0.16	0.43
6D(-1) & 8D(-1)	52	0.25	0.63	5	0.32	0.65	6	0.57	1.28
6D(-2) & 8D(-2)	47	0.09	0.32	4	0.02	0.23	4	-0.24	0.16

RUNS 1, 3, 5 & 7

No. Intervals	:	*112*
Range	:	*-1.23/+2.09*
Mean	:	*0.41*
Std. Dev.	:	*0.61*

RUNS 2C, 4C, 6C, & 8C

No. Intervals	:	*104*
Range	:	*-0.95/+1.49*
Mean	:	*0.16*
Std. Dev.	:	*0.37*

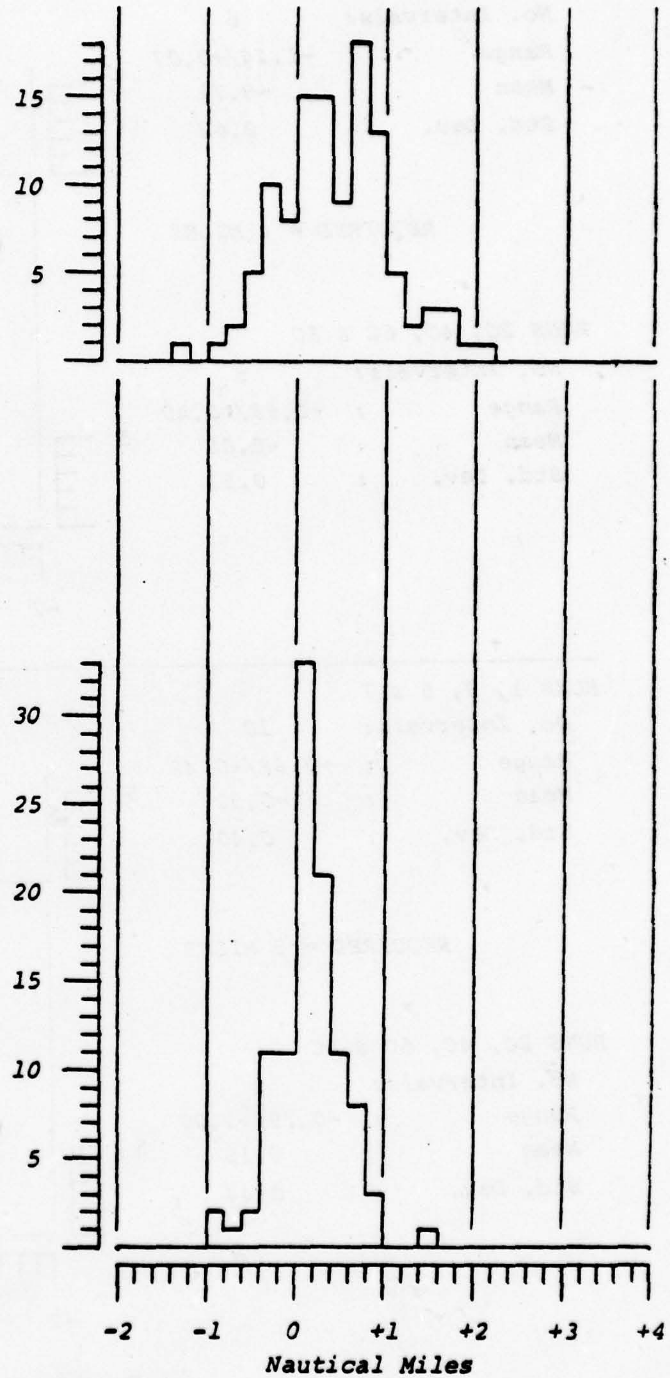


Exhibit 6-5

EXPERIENCED VS. REQUIRED FINAL APPROACH SPACING DISTRIBUTION

(REQUIRED = 3 MILES)

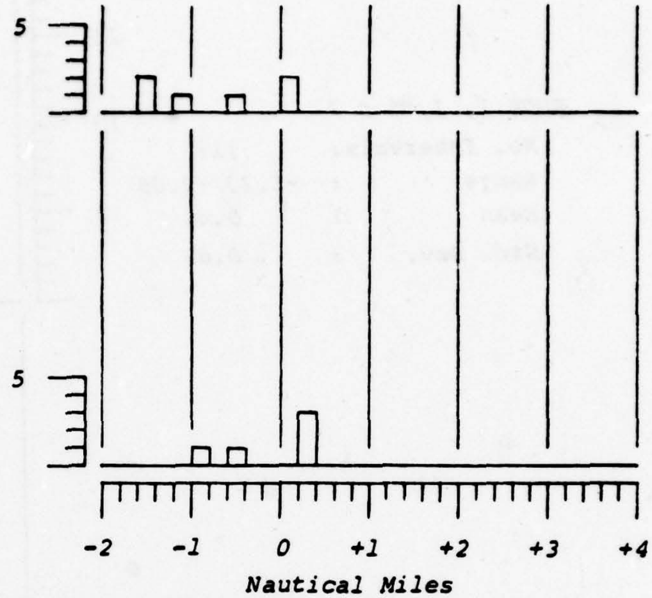
RUNS 1, 3, 5 & 7

No. Intervals:		6
Range	:	-1.44/+0.07
Mean	:	-0.71
Std. Dev.	:	0.63

REQUIRED = 4 MILES

RUNS 2C, 4C, 6C & 8C

No. Intervals:		5
Range	:	-0.88/+0.40
Mean	:	-0.08
Std. Dev.	:	0.51



RUNS 1, 3, 5 & 7

No. Intervals:		10
Range	:	-0.88/+0.42
Mean	:	-0.32
Std. Dev.	:	0.40

REQUIRED = 5 MILES

RUNS 2C, 4C, 6C & 8C

No. Intervals:		8
Range	:	-0.29/+1.00
Mean		0.15
Std. Dev.	:	0.44

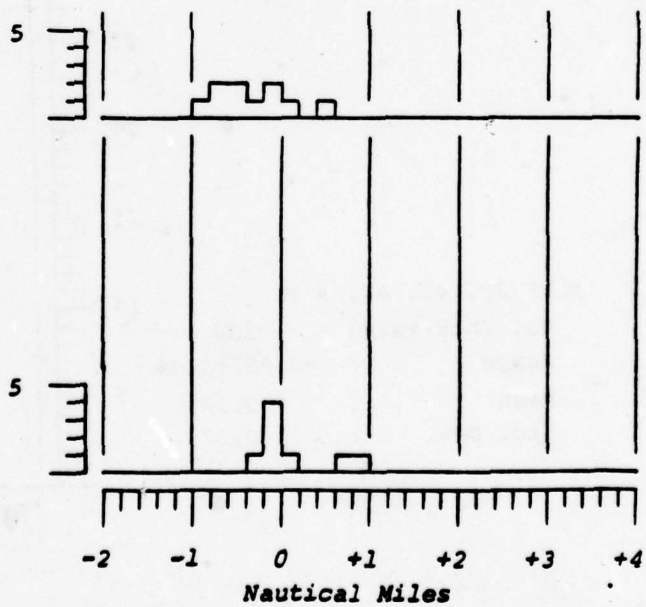


Exhibit 6-6

EXPERIENCED VS. REQUIRED FINAL APPROACH SPACING DISTRIBUTION
(REQUIRED = 4 & 5 MILES)

RUNS 5 & 7

No. Intervals	:	51
Range	:	-1.23/+1.85
Mean	:	0.24
Std. Dev.	:	0.62

RUNS 6C & 8C

No. Intervals	:	51
Range	:	-0.95/+0.87
Mean	:	0.09
Std. Dev.	:	0.35

RUNS 6D(-1) & 8D(-1)

No. Intervals	:	52
Range	:	-0.88/+2.68
Mean	:	0.25
Std. Dev.	:	0.63

RUNS 6D(-2) & 8D(-2)

No. Intervals	:	47
Range	:	-0.88/+0.77
Mean	:	0.09
Std. Dev.	:	0.32

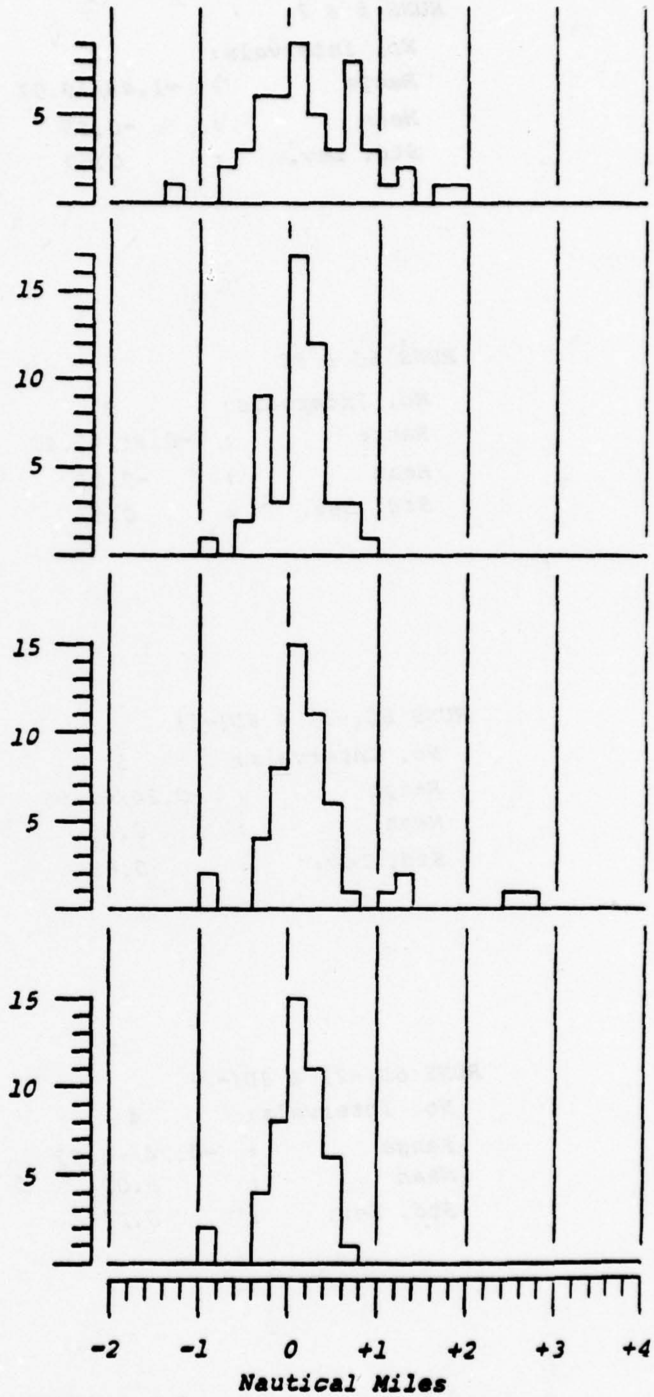


Exhibit 6-7

EXPERIENCED VS. REQUIRED FINAL APPROACH SPACING DISTRIBUTION
(REQUIRED = 3 MILES)

RUNS 5 & 7

No. Intervals	:	4
Range	:	-1.43/+0.07
Mean	:	-0.45
Std. Dev.	:	0.60

RUNS 6C & 8C

No. Intervals	:	3
Range	:	-0.88/+0.40
Mean	:	-0.08
Std. Dev.	:	0.57

RUNS 6D(-1) & 8D(-1)

No. Intervals	:	5
Range	:	-0.24/+1.56
Mean	:	0.32
Std. Dev.	:	0.65

RUNS 6D(-2) & 8D(-2)

No. Intervals	:	4
Range	:	-0.24/+0.23
Mean	:	0.02
Std. Dev.	:	0.23

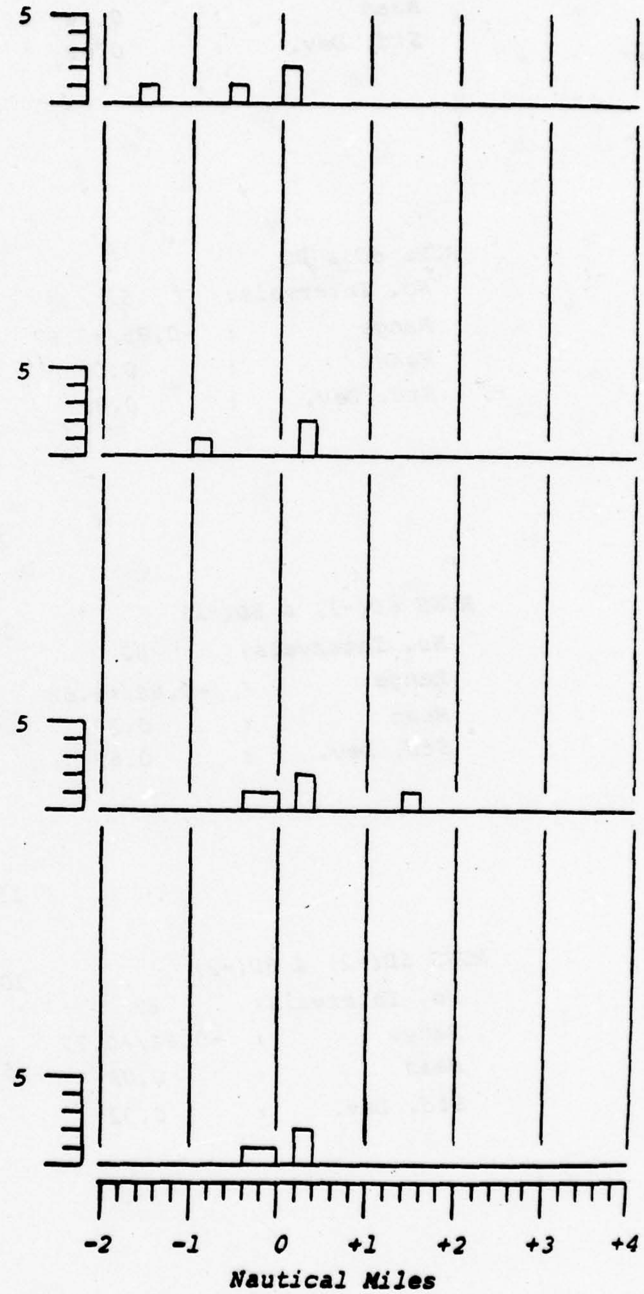


Exhibit 6-8

EXPERIENCED VS. REQUIRED FINAL APPROACH SPACING DISTRIBUTION (REQUIRED = 4 MILES)

RUNS 5 & 7

No Intervals: 6
Range: -0.77/+0.42
Mean: -0.21
Std. Dev.: 0.42

RUNS 6C & 8C

No. Intervals: 5
Range: -0.18/+1.00
Mean: 0.16
Std. Dev.: 0.43

RUNS 6D(-1) & 8D(-1)

No. Intervals: 6
Range: -0.51/+3.17
Mean: 0.57
Std. Dev.: 1.28

RUNS 6D(-2) & 8D(-2)

No. Intervals: 4
Range: -0.51/-0.10
Mean: -0.24
Std. Dev.: 0.16

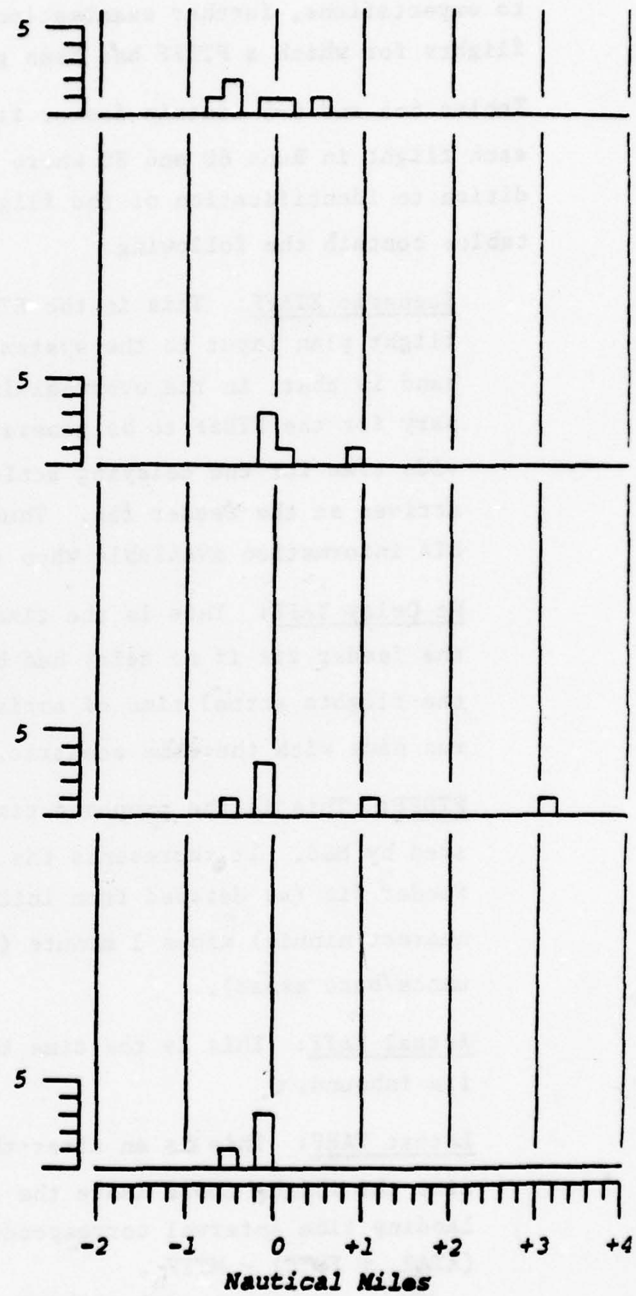


Exhibit 6-9

EXPERIENCED VS. REQUIRED FINAL APPROACH SPACING DISTRIBUTION
(REQUIRED = 5 MILES)

In the (-1) assessment of the metered runs, it was found that end results, as reflected in the key performance measures, were considerably poorer than those of the corresponding unmetered runs. Since this was contrary to expectations, further examination was made of the data on those flights for which a PTDFF had been generated by M&S.

Tables 6-5 and 6-6 contain feeder fix time and delay data pertinent to each flight in Runs 6D and 8D where a PTDFF was generated by M&S. In addition to identification of the flight and the feeder fix involved, these tables contain the following:

Scenario ETAFF: This is the ETA at the feeder fix as provided in the flight plan input to the system. Its importance in the question at hand is that, in the overwhelming majority of the cases, it is necessary for the PTDFF to be generated prior to track initiation to provide time for the delaying action to be taken before the aircraft arrives at the feeder fix. Thus, it generally constitutes the only ETA information available when the PTDFF is generated.

No Delay TAFF: This is the time the aircraft could have arrived at the feeder fix if no delay had been imposed. It corresponds to the flights actual time of arrival at the feeder fix in the unmetered run made with the same scenario.

PTDFF: This is the proposed time to depart the feeder fix as generated by M&S. It represents the flight's "on schedule" time at the feeder fix (as derived from initial scheduling and rounded to the nearest minute) minus 1 minute (to reserve some delay for the sequence/base areas).

Actual TAFF: This is the time the flight actually passed the feeder fix inbound.

Latest TAFF: This is an after-the-fact determination of the latest time the flight could leave the feeder fix and still make good a landing time interval corresponding to the FSTC. Its derivation is $(ATAR_p + FSTC) - MTTF_n$.

FSTC Delay: This is the total delay required to meet the FSTC.

Table 6-5

FEEDER FIX TIME AND DELAY DATA FOR AIRCRAFT WHERE PTDFF WAS GENERATED BY M&S - RUN 6D

Ident.	FF	Scenario ETAFF	No Delay TAFF	PTDFF	Actual TAFF	Latest TAFF	FSTC Delay	Delay Experienced Total	Delay Experienced Before FF	Delay Experienced After FF
RMA217	BY3	10:21	10:19:50	10:24	10:22:46	10:24:36	286	280	176	104
FL81	IOC	10:31	10:31:09	10:34	10:33:54	10:35:46	277	267	165	102
WA215	KE3	10:34	10:34:05	10:37	10:36:57	10:38:59	294	295	172	123
WA485	DR3	10:37	10:36:40	10:39	10:38:16	10:39:52	192	205	96	109
UA280	BY3	10:35	10:34:33	10:37	10:36:31	10:39:37	304	282	118	164
FL407	KE3	10:42	10:42:10	10:44	10:44:15	10:45:06	176	172	125	47
WA554	BY3	10:39	10:38:33	10:41	10:40:43	10:42:42	249	251	130	121
BN990	IOC	10:44	10:43:59	10:46	10:46:05	10:47:32	213	214	126	88
UA182	DR3	10:44	10:43:10	10:46	10:45:16	10:47:18	248	267	126	141
CO420	DR3	10:45	10:44:40	10:48	10:48:24	10:49:45	305	303	244	59
UA408	DR3	10:46	10:46:10	10:50	10:50:20	10:51:05	305	306	250	56
* N743JA	IOC	10:51	10:46:34	10:50	10:51:10←	→10:50:39	245	288	276	12
CO265	IOC	11:11	11:10:59	11:13	11:13:07←	→11:12:08	69	135	128	7
TW193	KE3	11:12	11:12:05	11:14	11:14:05	11:14:52	167	162	120	42

*The PTDFF for N743JA was generated after tracking had been initiated. At that time the M&S updated ETAFF was 10:46. In this case the aircraft was given a 360° turn to absorb the delay rather than a late start.

Legend:

No Delay TAFF = Time flight could have reached the feeder fix with no delay (taken from corresponding unmetered run).

Latest TAFF = $(ATAR_p + FSTC) - MTTF_n$

FSTC Delay = Delay required to meet FSTC = $(ATAR_p + FSTC) - (\text{No Delay } TAFF_n + MTTF_n)$

Delay Experienced (Total) = $ATAR_n - (\text{No Delay } TAFF_n + MTTF_n)$

(Before FF) = Actual TAFF - No Delay TAFF.

(After FF) = Total Delay - Delay Before FF.

Table 6-6

FEEDER FIX TIME AND DELAY DATA FOR AIRCRAFT WHERE PTDFF WAS GENERATED BY M&S - RUN 8D

Ident.	FF	Scenario ETAFF	No Delay TAFF	PTDFF	Actual TAFF	Latest TAFF	FSTC Delay	Delay Experienced Total	Delay Experienced Before FF	Delay Experienced After FF
TI2888	IOC	10:16	10:15:10	10:19	10:18:10	10:21:07	357	360	180	180
RMA217	BY3	10:15	10:12:57	10:19	10:17:03	10:20:32	455	461	246	215
TW173	IOC	10:22	10:21:12	10:26	10:25:25	10:27:33	381	382	253	129
TW457	IOC	10:24	10:22:42	10:27	10:26:14	10:28:59	377	382	212	170
WA485	DR3	10:33	10:33:24	10:35	10:36:04←	→10:35:35	131	160	160	0
CO24	BY3	10:30	10:29:15	10:33	10:32:23	10:34:34	319	328	188	140
WA215	KE3	10:34	10:34:21	10:37	10:37:20	10:37:58	217	209	179	30
FL81	IOC	10:31	10:30:17	10:35	10:34:16	10:36:47	390	403	239	164
UA280	BY3	10:35	10:34:15	10:38	10:37:22	10:39:01	286	298	187	111
FL407	KE3	10:39	10:39:27	10:43	10:43:29←	→10:43:21	234	265	242	23
WA554	BY3	10:39	10:38:15	10:41	10:40:22	10:43:31	316	323	127	196
UA182	DR3	10:44	10:43:54	10:47	10:47:06	10:48:02	248	248	192	56
UA408	DR3	10:47	10:46:54	10:51	10:51:32←	→10:50:16	202	278	278	0
CO420	DR3	10:45	10:45:24	10:50	10:51:30	10:52:57	453	456	366	90
CO964	DR3	10:48	10:48:24	10:54	10:55:02←	→10:54:28	364	398	398	0
BN990	IOC	10:44	10:43:07	10:51	10:50:32	10:53:40	633	629	445	184
TW186	BY3	10:50	10:49:19	10:55	10:54:35	10:55:42	383	390	316	74
UA226	DR3	10:50	10:49:54	10:57	10:57:58	11:00:08	614	615	484	131
N4643G	DR3	10:50	10:50:26	10:56	10:57:17	10:59:42	556	551	411	140
OZ991	KE3	10:54	10:54:21	11:02	11:02:17	11:03:26	545	557	476	81
UA346	DR3	10:55	10:54:54	11:04	11:04:02	11:06:11	677	678	548	130
UA434	BY3	10:52	10:50:51	11:05	11:04:23	11:04:41	830	828	812	16
N743JA	IOC	10:45	10:45:18	10:57	10:57:24	11:00:06	888	896	726	170
UA174	BY3	10:53	10:52:19	11:07	11:06:23	11:09:42	1043	1039	844	195
TW193	KE3	10:59	10:59:21	11:11	11:11:37	11:12:54	813	814	736	78
TW219	KE3	11:01	11:01:21	11:14	11:14:33←	→11:14:20	779	819	792	27
CO265	IOC	10:59	10:58:07	11:11	11:10:05	11:13:58	951	949	718	231
UA210	BY3	11:06	11:05:15	11:18	11:17:07←	→11:15:56	641	712	712	0

Legend: (See Run 6D)

Delay Experienced: This is the delay actually experienced broken down to reflect the total delay, the delay experienced before reaching the feeder fix and the delay experienced after leaving the feeder fix.

The arrows between the Actual TAFF and Latest TAFF columns identify those cases where the flight's actual time of arrival at the feeder fix was later than the latest time the flight could have arrived and made good an LTI corresponding to the FSTC value thus resulting in a gap. Since the No Delay TAFF was earlier than the Latest TAFF, the gap was created by the metering process rather than being an unavoidable break resulting from natural gaps in the traffic demand. Consequently, in the (-1) assessment, the gaps represent positive LTI errors and are included as such in the statistical summaries of the run.

Inasmuch as the results of the metering process reflect the net effect of three basic factors involved in the process, a further examination was made to determine the contribution of each. The factors involved and their relationship to the process are as follow:

Accuracy of ETAs: As previously noted, in the overwhelming majority of the cases, the ETA from the flight plan data is the only ETA data available at the time the PTDFF must be generated. Since it is used by M&S in initial scheduling to determine what schedule can be made good, errors in the ETA can have impact on the outcome of the metering process, particularly if the ETA indicates the aircraft will arrive considerably earlier than its true No Delay TAFF.

Effectiveness of the Metering Procedure in Achieving the PTDFF: The concept of metering embodied in the Basic M&S design was that the PTDFF messages would be automatically transmitted to the enroute system to be acted upon by the enroute controllers having control of the flights. Just exactly what procedures would be employed or what delivery accuracy could be expected has not been precisely determined. For the simulation tests, conducted without benefit of an interfaced enroute system, the aim was to simulate the effects of enroute metering, not the method. The procedure was for test

personnel to monitor a tabular list of aircraft inbound to the feeder fixes. When a PTDFF display was generated by M&S for one of these aircraft, the amount of delay was determined by subtracting the ETA from the PTDFF and this time was added to the original start up time for the target as carried in a scenario log. The target generator operator in the DSF was instructed to disable the automatic start up feature of the target generator and to start the target on a command later issued by test personnel in the TATF.

Irrespective of the procedure applied, it is evident that imperfections in delivery, particularly if aircraft are delivered later than desired, impact the outcome of the metering process.

Accuracy of the PTDFF: The PTDFF represents the targeted time for the aircraft to cross the feeder fix, thus, imperfections in this value can obviously impact the outcome.

Table 6-7 and 6-8 contain data regarding the contribution of each of the above factors to the net effect for each of the aircraft where a PTDFF was generated. These data are also presented in the form of histograms in Exhibit 6-10. As in the previous tables, the arrows alongside the Net Effect column in the tables indicates those instances where the metering process resulted in a gap.

A number of inferences may be drawn from these data; however, caution must be exercised in making any particular judgement. For example:

a. These data indicate the aircraft's no-delay time of arrival at the feeder fix ranged from 123 seconds earlier to 27 seconds later (excluding N743JA, Run 6D) than it's flight plan ETA. Whether this is representative of field performance has not been verified, however, the M&S design criteria assumes a value of +/- 60 seconds. In the case in point, the more critical value (+27 seconds) is well within this tolerance.

b. The effectiveness of the procedure in achieving the delay it was intended to ranged from 24 seconds less than intended to 66 seconds more than intended. Just what accuracies are achieved

Table 6-7

IMPERFECTIONS IN THE METERING PROCESS - RUN 6D

Ident.	FF	Imperfections ETA	Proc.	PTDFF	Net Effect
RMA217	BY3	-70	-4	-36	-110
FL81	IOC	+9	-15	-106	-112
WA215	KE3	+5	-8	-119	-122
WA485	DR3	-20	-24	-52	-96
UA280	BY3	-27	-2	-157	-186
FL407	KE3	+10	+5	-66	-51
WA554	BY3	-27	+10	-102	-119
BN990	IOC	-1	+6	-92	-87
UA182	DR3	-50	+6	-78	-122
CO420	DR3	-20	+44	-105	-81
UA408	DR3	+10	+10	-65	-45
N743JA	IOC	+34	+36	-39	+31 ←
CO265	IOC	-1	+8	+52	+59 ←
TW193	KE3	+5	0	-52	-47

Legend:

ETA = No Delay TAFF - ETAFF. Indicates imperfections in ETA accuracy in seconds. (-) indicates the No Delay TAFF was earlier than the ETAFF and (+) indicates it was later.

Proc. = (Actual TAFF - No Delay TAFF) - (PTDFF - ETAFF). Indicates imperfections in the simulation procedure in achieving its intent. Values are expressed in seconds. (-) indicates the aircraft was delayed less than intended and (+) indicates it was delayed more than intended.

PTDFF = PTDFF - Latest TAFF. Indicates whether PTDFF (if met) would have reserved some delay to be absorbed in the sequence and base areas. Values are expressed in seconds. (-) indicates delay remaining to be absorbed. (+) indicates the PTDFF (if met) would result in the aircraft being delayed more than necessary.

Net Effect = Actual TAFF - Latest TAFF. Indicates the end results of the metering process. Values are expressed in seconds. (-) indicates the remaining time to be absorbed in the sequence and base areas. (+) indicates the process created a gap.

Table 6-8

IMPERFECTIONS IN THE METERING PROCESS - RUN 8D

Ident.	FF	ETA	Proc.	PTDFF	Net Effect	
TI2888	IOC	-50	0	-127	-177	
RMA217	BY3	-123	+6	-92	-209	
TW173	IOC	-48	+13	-83	-118	
TW457	IOC	-78	+32	-119	-165	
WA485	DR3	+24	+40	-35	+29	←
CO24	BY3	-45	+8	-94	-131	
WA215	KE3	+21	-1	-58	-38	
FL81	IOC	-43	-1	-107	-151	
UA280	BY3	-45	+7	-61	-99	
FL407	KE3	+27	+2	-21	+8	←
WA554	BY3	-45	+7	-151	-189	
UA182	DR3	-6	+12	-62	-56	
UA408	DR3	-6	+38	+44	+76	←
CO420	DR3	+24	+66	-177	-87	
CO964	DR3	+24	+38	-28	+34	←
BN990	IOC	-53	+25	-160	-188	
TW186	BY3	-41	+16	-42	-67	
UA226	DR3	-6	+64	-188	-130	
N4643G	DR3	+26	+51	-222	-145	
OZ991	KE3	+21	-4	-86	-69	
UA346	DR3	-6	+8	-131	-129	
UA434	BY3	-69	+32	+19	-18	
N743JA	IOC	+18	+6	-186	-162	
UA174	BY3	-41	+4	-162	-199	
TW193	KE3	+21	+16	-114	-77	
TW219	KE3	+21	+12	-20	+13	←
CO265	IOC	-53	-2	-178	-233	
UA210	BY3	-45	-8	+124	+71	←

Legend: (See Run 6D)

ETA

No. : 42
Range: -123/+34
Mean : -17.12
S.D. : 35.83

PROCEDURE

No. : 42
Range: -24/+66
Mean : +13.31
S.D. : 19.90

PTDFF

No. : 42
Range: -222/+124
Mean : -84.14
S.D. : 69.31

NET EFFECT

No. : 42
Range: -233/+76
Mean : -87.95
S.D. : 79.47

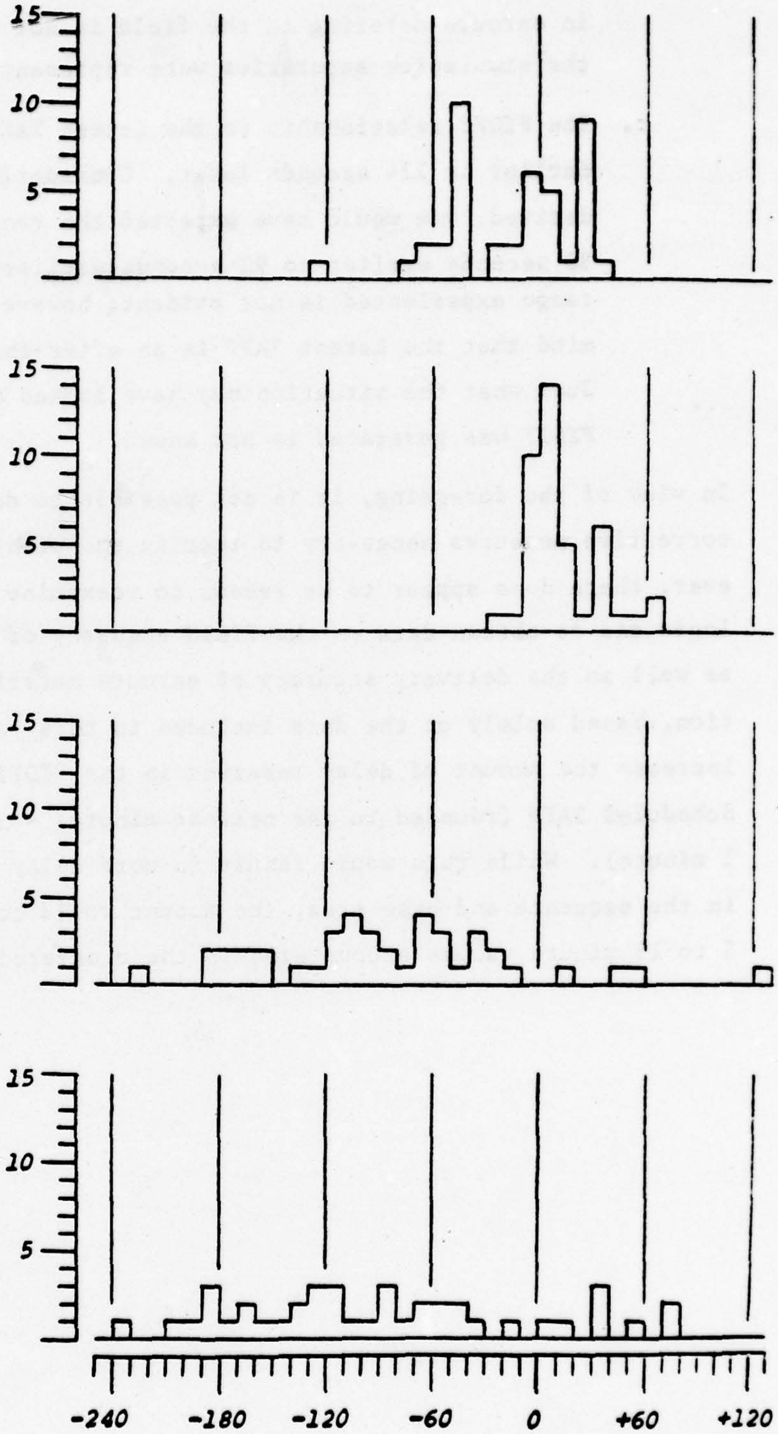


Exhibit 6-10

IMPERFECTIONS IN THE METERING PROCESS - RUNS 6D AND 8D

in enroute metering in the field is not known, thus, whether the simulation accuracies were representative is also unknown.

c. The PTDFF relationship to the Latest TAFF ranged from 222 seconds earlier to 124 seconds later. Considering how the PTDFF is derived, one would have expected the range to be on the order of 30 seconds earlier to 90 seconds earlier. The cause of the wide range experienced is not evident; however, it must be kept in mind that the Latest TAFF is an after-the-fact determined value. Just what the situation may have looked like at the time the PTDFF was generated is not known.

In view of the foregoing, it is not possible to define specifically the corrective measures necessary to rectify the problems encountered. However, there does appear to be reason to reexamine the PTDFF generation logic and to obtain data on the field accuracy of ETAs at feeder fixes as well as the delivery accuracy of enroute metering. An interim solution, based solely on the data included in this analysis, would be to increase the amount of delay reserved in the PTDFF, e.g., PTDFF = Scheduled TAFF (rounded to the nearest minute) - 3 minutes (instead of 1 minute). While this would result in more delay having to be absorbed in the sequence and base area, the amount would come no where near the 5 to 15 minute values encountered in the unmetered runs.

7. STATISTICAL SIGNIFICANCE OF RESULTS

7.1 Definition of Problem

The assessment of statistical significance of test results, as previously noted in 6.2.1, rests most critically upon the differences observed in the standard deviations of the LTI errors obtained from the test runs. Major emphasis was placed on the analysis of the significance of those differences, although the significance of the difference between mean LTI error values was also calculated.

The most sensitive method of assessing these differences was to use the F-test of variance (the square of the standard deviation) and the t-test on means. Both of these tests, however, are based on the assumption that the parent populations of the samples are normally distributed. Before the sensitivity of these tests could be utilized, it was therefore necessary to determine whether the samples involved could be assumed to have been drawn from normally distributed parent populations.

Measurements of the curve shape parameters of kurtosis and skewness indicate that all unmetered runs might come from normal distributions, since the kurtosis and skewness values obtained from these runs approximated those of a normal distribution. The kurtosis and skewness values for the metered runs, however, were very different from the normal values, and do not support assumptions of normal distributions. All these measurements are discussed in Appendix D.

As a further check of the normality of the unmetered runs, goodness-of-fit chi-square tests were performed on the combined manual runs sample and the combined unmetered M&S sample. Test results showed a very close fit between the combined manual runs sample and a normal distribution; if samples of the same size had been drawn from a normally distributed parent population, 9 out of 10 of them would exhibit worse fits than the combined manual runs sample. On the other hand, this was not so in the case of the combined unmetered M&S sample; in that case, if samples of the same size had been drawn from a normally distributed parent population, only 1 out of every 100 of them would have exhibited worse fits. The chi-square tests are described in Appendix E.

This question of normally distributed parent populations was then addressed in a third way. Two separate tests on variance were applied to various sample comparisons; the classical F-test, which assumes normal distributions, and the Miller Jackknife test, which does not. As illustrated in Table 7-1, the results from the two tests were consistent with each other. This was taken as a reliable indication of the basic normality of the parent populations. The t-test on means was therefore performed on the sample comparisons in the usual manner.

Descriptions of the tests are presented in Appendix F, for the F-test; Appendix G, for the Miller Jackknife test; and Appendix H, for the t-test.

All sample comparisons were made with matched runways and traffic scenarios.

7.2 Results of Statistical Tests

The determination of statistical significance is normally taken to mean the computation of the probability that observed differences in the parameter of interest could have occurred by chance alone, and not as a result of different sample treatments or anything else. For example, if there is a case where this probability is 1%, then there is a 99% probability that something else, other than chance (presumably the different sample treatments) was involved in the production of those differences. The 99% figure is termed the "level of confidence" resulting from the particular statistical comparison.

In discussing the comparison of various LTI error sample combinations, it is worthwhile to note that five of the comparisons made were significant at the 99% level of confidence -- a rather high confidence level compared to confidence levels commonly used. The five comparisons are listed below:

(1) Unmetered M&S runs, in two comparisons, have had smaller variances than the manual runs. ((1,3,5,7) vs. (2C,4C,6C,8C); (5,7) vs. (6C,8C))

(2) The metered (-1) M&S runs had a larger variance than the unmetered M&S runs. ((6D-1,8D-1) vs. (6C,8C))

(3) The metered M&S (-1) runs had a larger variance than the metered M&S (-2) runs. ((6D-1,8D-1) vs. (6D-2,8D-2))

Table 7-1

TESTS OF VARIANCE

SAMPLE 1		SAMPLE 2		Below What Confidence Level are the Observed Differences Significant?	
Identity	*Variance*	*Identity*	*Variance*	*F-test*	*Miller Jackknife Test*
(1,3,5,7)	292.49	(2C,4C,6C,8C)	102.29	99%	99%
(5,7)	271.14	(6C,8C)	100.31	99%	99%
(6D-1,8D-1)	357.25	(6C,8C)	100.31	99%	99%
(6D-1,8D-1)	357.25	(6D-2,8D-2)	70.20	99%	99%
(6C,8C)	100.31	(6D-2,8D-2)	70.20	80%	70%
(5,7)	271.14	(6D-2,8D-2)	70.20	99%	99%

(4) The metered M&S (-2) runs had a smaller variance than the manual runs. ((5,7) vs. (6D-2,8D-2))

At lower confidence levels, other comparisons also exhibit statistical significance. Tables 7-1 and 7-2 list the confidence levels for each comparison made, below which the observed differences can be said to be significant.

Table 7-2

TEST OF MEANS

SAMPLE 1		SAMPLE 2		Below What Confidence Level are the Observed Differences Significant?
Identity	Mean	Identity	Mean	t-test
(1,3,5,7)	8.03	(2C,4C,6C,8C)	3.76	97.5%
(5,7)	4.08	(6C,8C)	2.39	50%
(6D-1,8D-1)	7.24	(6C,8C)	2.39	90%
(6D-1,8D-1)	7.24	(6D-2,8D-2)	1.20	95%
(6C,8C)	2.39	(6D-2,8D-2)	1.20	95%
(5,7)	4.08	(6D-2,8D-2)	1.20	75%

8. CONCLUSIONS

Table 8-1 contains a summary of the analysis results. An examination of the data in this table will support the following conclusions:

- The terminal control system, when operated with M&S and an unmetered traffic flow, exhibited LTI error, landing rate, system delay and minimum spacing performance that was superior to the performance exhibited when the system was operated without M&S.
- When the metering function was applied with M&S, performance in all the performance measurement areas was degraded by the occurance of errors in the metering process.
- Even with the errors experienced in the metering process, system performance when operated with M&S and metering was comparable, by most measures of performance, to the performance exhibited when the system was operated without M&S.
- The most favorable results reflected for any of the test runs are those of the metered runs with M&S where the effects of metering errors had been removed. This indicates that, if the problems encountered in the metering process are rectified, the performance of the system when operating with both the metering and spacing functions of M&S will be superior to the performance realized when operating without the metering function.

Table 8-1

ANALYSIS RESULTS SUMMARY

Measurements	WITHOUT M&S	WITH M&S		
			Metered	
		Unmetered	Metering Errors Included	Metering Errors Deleted
LTI Error (seconds):				
Mean	8.03	3.76	7.24	1.20
Standard Deviation	17.04	10.07	18.75	8.31
Safe Landing Rate (Acft. per hour)	28.87	32.51	28.10	33.31
Av. System Delay per Acft. at Safe Landing Rate (seconds)	34.08	20.14	37.50	16.62
Minimum Spacing (Naut. Miles)				
3 Miles Required				
Mean	3.41	3.16	3.25	3.09
Standard Deviation	0.61	0.37	0.63	0.32
4 Miles Required				
Mean	3.29	3.92	4.32	4.02
Standard Deviation	0.63	0.51	0.65	0.23
5 Miles Required				
Mean	4.68	5.15	5.57	4.76
Standard Deviation	0.40	0.44	1.28	0.16

9. RECOMMENDATIONS

The M&S test runs included in this analysis were made primarily to enable an early determination of whether certain changes introduced in the program would provide a noticeable improvement in overall performance. This step is part of a planned group of test and evaluation activities intended to lead to and include an R&D field trial of the system at Denver. The test results, as reflected in this report, strongly support the continuation of that approach. While it is true that some problems were uncovered in the metering process, and these do warrant further investigation, they should not deter progress toward carrying out the field trials at Denver. In fact, the field trials should help gain insight into the proper trade-offs to be made in rectifying the problem.

It is therefore recommended that the T&E activities, including performance tests of M&S with the wind update modules enabled, be continued at NAFEC and that the system subsequently be subjected to field trial at Denver. The following views are offered in support of this recommendation:

> The purpose and importance of a field trial in an operational environment while a system is still undergoing development are often misunderstood and confused with first article demonstrations where the development has essentially been completed. When this occurs, the system is expected to exhibit performance deemed necessary for operational implementation. In contrast, the real purpose and importance of an R&D field trial is to afford the opportunity
>
> (1) for the people for whom the system is intended to try various aspects of the system in the real environment in which it is intended to perform so that they are in a position to provide informed recommendations on whether and how the system might be changed to best serve their needs, and,
>
> (2) for the developers to identify technical weaknesses of the system when exposed to the variations encountered in real world, day-to-day operations.
>
> Without downgrading the the value and essentiality of simulation tests, in a complex undertaking such as M&S, it can still be

expected that, despite best efforts to simulate real-world operations, an actual field trial will uncover the requirement for additional changes that will require substantial effort on the part of the developers. Thus, it should not be expected that performance exhibited during the field trial will be spectacular but rather that one will be able to determine the potential performance and acceptability if the weaknesses identified during the field trial period are corrected. Where these changes might be extensive, it is important that they be known during rather than at the conclusion of the development phase.

APPENDIX A

TRAFFIC SCENARIOS AND PERFORMANCE PROFILES

Table A-1

TRAFFIC SAMPLE A1738 & A2638

All High Performance (2 Heavy; 35 Large; 1 Small)

Feeder Fix	ETA FF (A1738)	ETA FF (A2638)	Acft. Ident.	Type	Weight Cat.	Perf. Cat.	Profile IAS Cruise	Maneuvering	Final	Decel. Rate (K/Min)	Descent Rate (fpm)
KE3	10:03	10:03	OZ979	DC9	L	Hi	250+	250-160	130	45	1500
KE3	10:04	10:04	FL103	B737	L	Hi	250+	250-160	130	45	2500
IOC	10:05	10:05	CO266	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:05	10:05	UA456	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:10	10:07	UA832	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:12	10:11	WA472	B737	L	Hi	250+	250-160	130	45	2500
DR3	10:09	10:09	UA718	B727	L	Hi	250+	250-160	130	45	1500
DR3	10:14	10:13	CO724	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:15	10:11	TI992	DC9	L	Hi	250+	250-160	130	45	1500
IOC	10:17	10:17	BN982	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:18	10:20	UA223	DC10	H	Hi	250+	250-160	140	60	2500
KE3	10:21	10:22	UA799	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:19	10:19	UA176	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:24	10:20	CO52	B727	L	Hi	250+	250-160	130	45	1500
DR3	10:26	10:22	A94617	F106	L	Hi	250+	250-190	170	45	2500
DR3	10:28	10:24	FL88	B737	L	Hi	250+	250-160	130	45	2500
DR3	10:30	10:26	UA760	B727	L	Hi	250+	250-160	130	45	1500
DR3	10:33	10:28	N111WJ	LR24	S	Hi	250+	250-160	140	60	2500
IOC	10:31	10:31	BN86	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:32	10:35	CO989	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:34	10:34	CO45	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:34	10:38	OZ531	DC9	L	Hi	250+	250-160	130	45	1500
KE3	10:36	10:39	WA219	B737	L	Hi	250+	250-160	130	45	2500
BY3	10:38	10:41	UA730	DC10	H	Hi	250+	250-160	140	60	2500
DR3	10:39	10:39	UA946	DC8	L	Hi	250+	250-160	130	45	2500
IOC	10:45	10:41	TW561	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:42	10:42	TW185	B707	L	Hi	250+	250-160	130	45	2500
KE3	10:46	10:47	UA259	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:48	10:49	UA311	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:52	10:50	TW449	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:53	10:52	UA305	DC8	L	Hi	250+	250-160	130	45	2500
BY3	10:50	10:50	CO44	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:55	10:52	FL20	B737	L	Hi	250+	250-160	130	45	2500
DR3	10:54	10:54	V54298	RF4	L	Hi	250+	250-190	190	45	2500
DR3	10:58	10:59	WA483	B720	L	Hi	250+	250-160	130	45	2500
IOC	10:56	10:56	BN109	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:57	11:01	TW401	B707	L	Hi	250+	250-160	130	45	2500
IOC	10:59	11:04	FL21	B737	L	Hi	250+	250-160	130	45	2500

Table A-2

TRAFFIC SAMPLE D1741, A1741 & A2641

38 High Performance; 3 Low Performance (4 Heavy; 33 Large; 4 Small)

								Profile IAS				
Feeder Fix	ETA FF (D1741)	ETA FF (A1741)	ETA FF (A2641)	Acft. Ident.	Type	Weight Cat.	Perf. Cat.	Cruise	Maneuvering	Final	Decel. Rate (K/Min)	Descent Rate (fpm)
IOC	10:04	10:04	10:04	BN62	B727	L	Hi	250+	250-160	130	45	1500
DR3	10:05	10:05	10:05	WA55	B737	L	Hi	250+	250-160	130	45	2500
IOC	10:08	10:08	10:08	CO721	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:08	10:08	10:08	FL884	CV58	L	Hi	250	250-135	120	45	1200
BY3	10:09	10:09	10:09	ASP416	CV58	L	Hi	250	250-135	120	45	1200
BY3	10:15	10:19	10:21	RMA217	DHC6	S	Lo	190	190-120	90	45	750
KE3	10:13	10:16	10:13	UA927	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:16	10:23	10:16	TI2888	DC9	L	Hi	250+	250-160	130	45	1500
KE3	10:15	10:18	10:15	CO25	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:16	10:20	10:20	WA53	B737	L	Hi	250+	250-160	130	45	2500
KE3	10:18	10:21	10:21	UA751	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:19	10:23	10:23	UA175	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:21	10:27	10:26	UA1423	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:22	10:25	10:28	TW173	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:24	10:27	10:31	TW457	B707	L	Hi	250+	250-160	130	45	2500
KE3	10:23	10:27	10:29	UA161	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:30	10:30	10:34	CO24	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:31	10:35	10:31	FL81	B737	L	Hi	250+	250-160	130	45	2500
DR3	10:32	10:32	10:35	N60MB	DA10	S	Hi	250+	250-160	130	60	2500
DR3	10:33	10:33	10:37	WA485	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:34	10:38	10:34	WA215	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:35	10:35	10:35	UA280	DC86	H	Hi	250+	250-160	140	60	2500
BY3	10:39	10:39	10:39	WA554	B720	L	Hi	250+	250-160	130	45	2500
KE3	10:39	10:39	10:42	FL407	B737	L	Hi	250+	250-160	130	45	2500
IOC	10:45	10:55	10:51	N743JA	BE90	S	Lo	190	190-120	90	45	750
IOC	10:44	10:48	10:44	BN990	B727	L	Hi	250+	250-160	130	45	1500
DR3	10:44	10:44	10:44	UA182	DC10	H	Hi	250+	250-160	140	60	2500
DR3	10:47	10:47	10:46	UA408	B727	L	Hi	250+	250-160	130	45	1500
DR3	10:45	10:45	10:45	CO420	B727	L	Hi	250+	250-160	130	45	1500
DR3	10:48	10:48	10:54	CO964	DC10	H	Hi	250+	250-160	140	60	2500
DR3	10:50	10:52	11:07	N4643G	C414	S	Lo	190	190-120	100	45	1000
DR3	10:50	10:53	10:57	UA226	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:50	10:50	10:58	TW186	B727	L	Hi	250+	250-160	130	45	1500
BY3	10:52	10:59	10:59	UA434	DC8	L	Hi	250+	250-160	130	45	2500
BY3	10:53	11:02	11:02	UA174	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:54	10:57	11:01	OZ991	DC9	L	Hi	250+	250-160	130	45	1500
DR3	10:55	10:55	11:05	UA346	B727	L	Hi	250+	250-160	130	45	1500
IOC	10:59	11:05	11:11	CO265	B727	L	Hi	250+	250-160	130	45	1500
KE3	10:59	11:06	11:12	TW193	B707	L	Hi	250+	250-160	130	45	2500
KE3	11:01	11:07	11:18	TW219	B707	L	Hi	250+	250-160	130	45	2500
BY3	11:06	11:10	11:19	UA210	DC86	H	Hi	250+	250-160	140	60	2500

APPENDIX B

KEY MEASUREMENT VALUES BY INDIVIDUAL TEST RUN

APPENDIX B

KEY MEASUREMENT VALUES BY INDIVIDUAL TEST RUN

- Explanatory Notes -

ETAR and ATAR are expressed as minutes and seconds after the hour. All other time values are expressed in seconds.

Interval measurements are between the aircraft identified in the line entry and the following aircraft.

The asterisks identify intervals that were excluded from statistical summaries, histograms and bar graphs. The double asterisk (**) is used to identify intervals where the OLTI is equal to the NDTC. Since NDTC is influenced by MTTF (Minimum Time To Fly) values which are somewhat imprecise, it was considered advisable to exclude error measurements where NDTC values were involved. The single asterisk (*) is used to identify intervals excluded due to a major error in simulation that was noted during the test or discovered during post-test analysis, or where data necessary to determine the proper values was missing. Following is a summary of the reasons for these exclusions:

Run No.	Reasons
1	BN86 and CO45: CO45 did not properly execute speed reductions. FL20 and V54298: V54298 did not properly execute speed reduction or descent.
3	OZ531: Another aircraft, CO45, was actually in the scenario and landed between OZ531 and WA219; however, DSF time-position history data was not available on this aircraft.
5	UA1423 and RMA217: In the TATF flight plan data, RMA217 was identified as a DH26 with FAS of 150 knots. In the DSF target generator program, RMA217 was identified as a DHC6 with final approach speed of 90 knots.
7	WA 53 and RMA217: Same as note following Run 5.
6C	WA215: N60MB is identified in the scenario as being in the "Small" weight class which requires a minimum spacing of four miles behind a preceding "Large" aircraft. Post test analysis revealed N60MB was being identified as "Large" in the M&S data base which requires a minimum spacing of only three miles behind a preceding "Large" aircraft. UA182, CO420 and UA408: During the course of this test run, a "manual resequence" keyboard entry was made by an observer causing a change in the sequence of CO420 and UA408 from that set up by the automated system. While the manual resequence function is a feature of the M&S system, its use during these tests was contrary to the ground rules.
8C	TW457: Same as the note following WA215, Run 6C. OZ991 and N743JA: Incomplete time-position history on N743JA.
6D (-1) 6D (-2)	FL81: Same as the note following WA215, Run 6C
8D (-1) 8D (-2)	TW457: Same as the note following WA215, Run 6C.

Table B-1

KEY MEASUREMENT VALUES - TEST RUN 1
TRAFFIC SAMPLE A2638 WITHOUT BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
12:43	13:05	22	OZ979	L	103	83	20	83	68	83	
14:13	14:48	35	FL103	L	97	82	15	82	-57	82	
13:51	16:25	154	CO266	L	128	89	39	89	17	89	
16:42	18:33	111	UA456	L	108	83	25	83	-27	83	
18:06	20:21	135	UA832	L	111	84	27	84	-137	84	
18:04	22:12	248	UA718	L	98	83	15	83	-126	83	
20:06	23:50	224	TI992	L	114	83	31	83	-73	83	
22:37	25:44	187	WA472	L	101	83	18	83	-191	83	
22:33	27:25	292	CO724	L	115	82	33	82	-108	82	
25:37	29:20	223	BN982	L	94	76	18	76	17	76	
29:37	30:54	77	UA223	H	136	139	-3	139	-3	139	
30:51	33:10	139	UA176	L	78	84	-6	84	-82	84	
31:48	34:28	160	UA799	L	58	62	-4	62	-217	62	
30:51	35:26	275	A94617	L	104	87	17	87	-184	87	
32:22	37:10	288	CO52	L	84	82	2	82	-236	82	
33:14	38:34	320	FL88	L	112	91	21	91	-200	91	
35:14	40:26	312	UA760	L	76	102	-26	102	-198	102	
37:08	41:42	274	N111WJ	S	104	89	15	89	-156	89	
39:06	43:26	260	BN86	L	84	82	2	82	-80	82	*
42:06	44:50	164	CO45	L	91	82	9	82	-74	82	*
43:36	46:21	165	CO989	L	124	112	12	81	112	81	**
48:13	48:25	12	OZ531	L	71	82	-11	82	23	82	
48:48	49:36	48	WA219	L	108	83	25	83	-82	83	
48:14	51:24	190	UA946	L	90	83	7	83	-108	83	
49:36	52:54	198	TW561	L	91	83	8	83	-71	83	
51:43	54:25	162	TW185	L	115	77	38	77	-99	77	
52:46	56:20	214	UA730	H	129	137	-8	137	53	137	
57:13	58:29	76	UA259	L	96	83	13	83	14	83	
58:43	00:05	82	UA311	L	92	83	9	83	8	83	
00:13	01:37	84	TW449	L	92	83	9	83	11	83	
01:48	03:09	81	UA305	L	92	82	10	82	-77	82	
01:52	04:41	169	CO44	L	84	82	2	82	-49	82	
03:52	06:05	133	FL20	L	23	55	-32	55	-198	55	*
02:47	06:28	221	V54298	L	109	98	11	98	-112	98	*
04:36	08:17	221	BN109	L	141	86	55	86	11	86	
08:28	10:38	130	WA483	L	91	83	8	83	-32	83	
10:06	12:09	123	TW401	L	115	82	33	82	-3	82	
12:06	14:04	118	FL21	L							

Table B-2

KEY MEASUREMENT VALUES - TEST RUN 3

TRAFFIC SAMPLE A1738 WITHOUT BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
14:04	14:19	15	OZ979	L	130	84	46	84	75	84	
15:34	16:29	55	FL103	L	98	83	15	83	-22	83	
16:07	18:07	120	UA456	L	88	84	4	84	-49	84	
17:18	19:35	137	CO266	L	105	101	4	101	-89	101	
18:06	21:20	194	UA718	L	111	84	27	84	-49	84	
20:31	23:11	160	UA832	L	111	83	28	83	-9	83	
23:02	25:02	120	WA472	L	94	84	10	84	-85	84	
23:37	26:36	179	CO724	L	107	85	22	85	58	85	
27:34	28:23	49	TI992	L	113	84	29	84	41	84	
29:04	30:16	72	BN982	L	71	78	-7	78	-77	78	
28:59	31:27	148	UA223	H	128	144	-16	144	-71	144	
30:16	33:35	199	UA176	L	101	84	17	84	-90	84	
32:05	35:16	191	UA799	L	92	62	30	62	-19	62	
34:57	36:48	111	A94617	L	118	114	4	114	-61	114	
35:47	38:46	179	CO52	L	89	85	4	85	-89	85	
37:17	40:15	178	FL88	L	91	84	7	84	-64	84	
39:11	41:46	155	UA760	L	103	83	20	83	47	83	
42:33	43:29	56	BN86	L	69	104	-35	104	-74	104	
42:15	44:38	143	N111WJ	S	113	89	24	89	-34	89	
44:04	46:31	147	CO989	L	88	84	4	84	-57	84	
45:34	47:59	145	OZ531	L	196	84	112	84	-55	84	*
47:04	51:15	251	WA219	L	101	84	17	84	-178	84	
48:17	52:56	279	UA946	L	95	78	17	78	-225	78	
49:11	54:31	320	UA730	H	128	148	-20	148	-87	148	
53:04	56:39	215	TW185	L	111	84	27	84	25	84	
57:04	58:30	86	TW561	L	79	85	-6	85	-56	85	
57:34	59:49	135	UA259	L	105	84	21	84	-45	84	
59:04	01:34	150	UA311	L	72	84	-12	84	-17	84	
01:17	02:46	89	CO44	L	68	56	12	56	4	56	
02:50	03:54	64	V54298	L	104	122	-18	122	-19	122	
03:35	05:38	123	TW449	L	80	84	-4	84	-94	84	
04:04	06:58	174	UA305	L	77	83	-6	83	-41	83	
06:17	08:15	118	FL20	L	94	85	9	85	-44	85	
07:31	09:49	138	WA483	L	108	84	24	84	-105	84	
08:04	11:37	213	BN109	L	91	84	7	84	-123	84	
09:34	13:08	214	TW401	L	103	84	19	84	-124	84	
11:04	14:51	227	FL21	L							

Table B-3

KEY MEASUREMENT VALUES - TEST RUN 5

TRAFFIC SAMPLE A2641 WITHOUT BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
12:06	14:27	141	BN62	L	134	94	40	94	-13	94	
14:14	16:41	147	WA55	L	101	83	18	83	-35	83	
16:06	18:22	136	CO721	L	168	99	69	87	99	87	**
20:01	21:10	69	FL884	L	121	88	33	88	21	88	
21:31	23:11	100	ASP416	L	83	83	0	83	-28	83	
22:43	24:34	111	UA927	L	101	82	19	82	14	82	
24:48	26:15	87	CO25	L	72	82	-10	82	-129	82	
24:06	27:27	201	TI2888	L	85	85	0	59	85	59	**
28:52	28:52	0	WA53	L	104	104	0	102	104	102	**
30:36	30:36	0	UA751	L	155	155	0	81	155	81	**
33:11	33:11	0	UA175	L	152	152	0	81	152	81	**
35:43	35:43	0	UA1423	L	240	195	45	195	185	195	*
38:48	39:43	55	RMA217	S	23	83	-60	83	-212	83	*
36:11	40:06	235	TW173	L	86	83	3	83	-98	83	
38:28	41:32	184	UA161	L	88	83	5	83	-171	83	
38:41	43:00	259	TW457	L	98	82	16	82	-223	82	
39:17	44:38	321	FL81	L	100	82	18	82	-55	82	
43:43	46:18	155	WA215	L	113	111	2	111	-125	111	
44:13	48:11	238	N60MB	S	72	82	-10	82	-139	82	
45:52	49:23	211	CO24	L	82	76	6	76	-173	76	
46:30	50:45	255	UA280	H	117	135	-18	135	-240	135	
46:45	52:42	357	WA485	L	100	83	17	83	-154	83	
51:48	54:22	154	FL407	L	89	81	8	81	-210	81	
50:52	55:51	299	WA554	L	101	84	17	84	-225	84	
52:06	57:32	326	BN990	L	71	76	-5	76	-264	76	
53:08	58:43	335	UA182	H	123	135	-12	135	-239	135	
54:44	00:46	362	CO420	L	84	83	1	83	-272	83	
56:14	02:10	356	UA408	L	173	184	-11	184	-150	184	
59:40	05:03	323	N743JA	S	71	76	-5	76	-85	76	
03:38	06:14	156	CO964	H	150	139	11	139	0	139	
06:14	08:44	150	UA226	L	104	81	23	81	73	81	
09:57	10:28	31	TW186	L	84	82	2	82	15	82	
10:43	11:52	69	OZ991	L	88	83	5	83	-25	83	
11:27	13:20	113	UA434	L	111	83	28	83	37	83	
13:57	15:11	74	UA174	L	101	83	18	83	-57	83	
14:14	16:52	158	UA346	L	194	194	0	151	194	151	**
20:06	20:06	0	N4643G	S	87	83	4	83	-60	83	
19:06	21:33	147	CO265	L	86	82	4	82	10	82	
21:43	22:59	76	TW193	L	185	185	0	59	185	59	**
26:04	26:04	0	TW219	L	234	234	0	71	234	71	**
29:58	29:58	0	UA210	H							

Table B-4

KEY MEASUREMENT VALUES - TEST RUN 7
TRAFFIC SAMPLE D1741 WITHOUT BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght.	Cat.	ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
14:15	14:45	30	WA55	L	125	99	26	99	47	99	
15:32	16:50	78	BN62	L	159	156	3	103	156	103	**
19:26	19:29	3	FL884	L	73	86	-13	86	7	86	
19:36	20:42	66	CO721	L	90	102	-12	102	14	102	
20:56	22:12	76	ASP416	L	126	110	16	85	110	85	**
24:02	24:18	16	UA927	L	123	110	13	85	110	85	**
26:08	26:21	13	CO25	L	114	86	28	86	75	86	
27:36	28:15	39	TI2888	L	66	84	-18	84	-43	84	
27:32	29:21	109	WA53	L	154	194	-40	194	154	194	*
31:55	31:55	0	RMA217	S	31	86	-55	86	-173	86	*
29:02	32:26	204	UA751	L	83	85	-2	85	-114	85	
30:32	33:49	197	UA175	L	80	87	-7	87	-107	87	
32:02	35:09	187	UA1423	L	95	85	10	85	-81	85	
33:48	36:44	176	UA161	L	81	85	-4	85	-186	85	
33:38	38:05	267	TW173	L	96	86	10	86	-177	86	
35:08	39:41	273	TW457	L	88	88	0	81	88	81	**
41:09	41:09	0	CO24	L	112	112	0	112	6	112	
41:15	43:01	106	N60MB	S	85	86	-1	86	-18	86	
42:43	44:26	103	FL81	L	81	87	-6	87	-101	87	
42:45	45:47	182	WA485	L	100	88	12	88	-45	88	
45:02	47:27	145	WA215	L	80	79	1	79	-74	79	
46:13	48:47	154	UA280	H	155	150	5	150	81	150	
50:08	51:22	74	FL407	L	113	87	26	87	-63	87	
50:19	53:15	176	WA554	L	82	78	4	78	-6	78	
53:09	54:37	88	UA182	H	142	154	-12	154	8	154	
54:45	56:59	134	CO420	L	106	86	20	86	-86	86	
55:33	58:45	192	BN990	L	76	85	-9	85	-150	85	
56:15	00:01	226	UA408	L	61	78	-17	78	-142	78	
57:39	01:02	203	CO964	H	145	147	-2	147	-107	147	
59:15	03:27	252	UA226	L	81	86	-5	86	-124	86	
01:23	04:48	205	TW186	L	161	197	-36	197	-145	197	
02:23	07:29	306	N4643G	S	104	85	19	85	-147	85	*
05:02	09:13	251	OZ991	L	51	86	-35	86	-298	86	
04:15	10:04	349	UA346	L	136	86	50	86	-431	86	
02:53	12:20	567	UA434	L	152	89	63	89	-477	89	*
04:23	14:52	629	UA174	L	77	84	-7	84	-259	84	
10:33	16:09	336	CO265	L	82	96	-14	96	-367	96	
10:02	17:31	449	TW193	L	106	87	19	87	-329	87	
12:02	19:17	435	TW219	L	89	78	11	78	-124	78	
17:13	20:46	213	UA210	H							

Table B-5

KEY MEASUREMENT VALUES - TEST RUN 2C

TRAFFIC SAMPLE A2638 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
13:25	13:42	17	OZ979	L	87	83	4	83	73	83	
14:55	15:09	14	FL103	L	76	83	-7	83	71	83	
16:20	16:25	5	CO266	L	123	120	3	83	120	83	**
18:25	18:28	3	UA456	L	116	105	11	82	105	82	**
20:13	20:24	11	UA718	L	57	83	-26	83	-34	83	
19:50	21:21	91	UA832	L	95	84	11	84	74	84	
22:35	22:56	21	TI992	L	119	107	12	81	107	81	**
24:43	24:55	12	CO724	L	65	83	-18	83	-35	83	
24:20	26:00	100	WA472	L	129	125	4	83	125	83	**
28:05	28:09	4	BN982	L	151	130	21	76	130	76	**
30:19	30:40	21	UA223	H	128	135	-7	135	110	135	
32:30	32:48	18	UA799	L	70	61	9	61	-9	61	
32:39	33:58	79	A94617	L	95	99	-4	99	-83	99	
32:35	35:33	178	UA176	L	79	81	-2	81	-88	81	
34:05	36:52	167	CO52	L	95	83	12	83	-89	83	
35:23	38:27	184	FL88	L	95	83	12	83	-64	83	
37:23	40:02	159	UA760	L	89	101	-12	101	-45	101	
39:17	41:31	134	N111WJ	S	82	86	-4	86	5	86	
41:36	42:53	77	BN86	L	92	92	0	82	92	82	**
44:25	44:25	0	CO45	L	98	98	0	84	98	84	**
46:03	46:03	0	CO989	L	157	157	0	82	157	82	**
48:40	48:40	0	OZ531	L	86	83	3	83	50	83	
49:30	50:06	36	WA219	L	98	82	16	82	17	82	
50:23	51:44	81	UA946	L	80	84	-4	84	21	84	
52:05	53:04	59	TW561	L	74	82	-8	82	-39	82	
52:25	54:18	113	TW185	L	76	76	0	76	11	76	
54:29	55:34	65	UA730	H	159	141	18	135	141	135	**
57:55	58:13	18	UA259	L	83	83	0	83	72	83	
59:25	59:36	11	UA311	L	92	83	9	83	79	83	
00:55	01:08	13	TW449	L	92	82	10	82	82	82	**
02:30	02:40	10	UA305	L	89	83	6	83	55	83	
03:35	04:09	34	CO44	L	60	55	5	55	22	55	
04:31	05:09	38	V54298	L	123	116	7	114	116	114	**
07:05	07:12	7	BN109	L	90	83	7	83	-97	83	
05:35	08:42	187	FL20	L	146	116	30	82	116	82	**
10:38	11:08	30	WA483	L	101	87	14	83	87	83	**
12:35	12:49	14	TW401	L	111	106	5	83	106	83	**
14:35	14:40	5	FL21	L							

Table B-6

KEY MEASUREMENT VALUES - TEST RUN 4C
TRAFFIC SAMPLE A1738 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
15:06	15:21	15	OZ979	L	87	84	3	84	74	84	
16:35	16:48	13	FL103	L	96	84	12	84	46	84	
17:34	18:24	50	UA456	L	92	85	7	85	57	85	
19:21	19:56	35	UA718	L	80	82	-2	82	-53	82	
19:03	21:16	133	CO266	L	100	83	17	83	43	83	
21:59	22:56	57	UA832	L	112	112	0	85	112	85	**
24:48	24:48	0	CO724	L	84	83	1	83	-19	83	
24:29	26:12	103	WA472	L	235	230	5	77	230	77	**
30:02	30:07	5	UA223	H	161	141	20	141	-49	141	
29:18	32:48	210	TI992	L	88	83	5	83	-120	83	
30:48	34:16	208	BN982	L	86	82	4	82	-152	82	
31:44	35:42	238	UA176	L	90	84	6	84	-156	84	
33:06	37:12	246	UA799	L	64	62	2	62	-96	62	
35:36	38:16	160	A94617	L	124	110	14	110	-62	110	
37:14	40:20	186	CO52	L	100	83	17	83	-107	83	
38:33	42:00	207	FL88	L	81	82	-1	82	-94	82	
40:26	43:21	175	UA760	L	110	102	8	102	4	102	
43:25	45:11	106	N111WJ	S	94	90	4	90	-53	90	
44:18	46:45	147	BN86	L	97	83	14	83	-9	83	
46:36	48:22	106	OZ531	L	86	84	2	84	-154	84	
45:48	49:48	240	CO989	L	92	83	9	83	-102	83	
48:06	51:20	194	WA219	L	110	83	27	83	-242	83	
47:18	53:10	352	CO45	L	102	85	17	85	-219	85	
49:31	54:52	321	UA946	L	74	76	-2	76	-252	76	
50:40	56:06	326	UA730	H	138	141	-3	141	-121	141	
54:05	58:24	259	TW185	L	108	85	23	85	12	85	
58:36	00:12	96	UA259	L	88	83	5	83	-7	83	
00:05	01:40	95	UA311	L	84	84	0	84	-172	84	
58:48	03:04	256	TW561	L	91	83	8	83	-20	83	
02:44	04:35	111	CO44	L	83	55	28	55	-74	55	
03:21	05:58	157	V54298	L	131	128	3	128	-83	128	
04:35	08:09	214	TW449	L	104	85	19	85	-183	85	
05:06	09:53	287	UA305	L	86	84	2	84	-129	84	
07:44	11:19	215	FL20	L	101	84	17	84	-153	84	
08:46	13:00	254	WA483	L	80	83	-3	83	-192	83	
09:48	14:20	272	BN109	L	88	84	4	84	-182	84	
11:18	15:48	270	TW401	L	94	84	10	84	-180	84	
12:48	17:22	274	FL21	L							

Table B-7

KEY MEASUREMENT VALUES - TEST RUN 6C
TRAFFIC SAMPLE A2641 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. &	Wght Cat.	ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
14:35	14:43	8	BN62	L	105	102	3	83	102	83	**
16:25	16:28	3	WA55	L	137	127	10	83	127	83	**
18:35	18:45	10	CO721	L	199	185	14	93	185	93	**
21:50	22:04	14	FL884	L	100	82	18	82	81	82	
23:25	23:44	19	UA927	L	85	94	-9	94	-24	94	
23:20	25:09	109	ASP416	L	91	82	9	82	21	82	
25:30	26:40	70	CO25	L	76	83	-7	83	-3	83	
26:37	27:56	79	TI2888	L	184	180	4	84	180	84	**
30:56	31:00	4	WA53	L	72	82	-10	82	25	82	
31:25	32:12	47	UA751	L	117	103	14	82	103	82	**
33:55	34:09	14	UA175	L	148	136	12	83	136	83	**
36:25	36:37	12	UA1423	L	132	123	9	83	123	83	**
38:40	38:49	9	TW173	L	107	83	24	83	21	83	
39:10	40:36	86	UA161	L	162	182	-20	182	-37	182	
39:59	43:18	199	RMA217	S	85	83	2	83	-93	83	
41:45	44:43	178	FL81	L	71	82	-11	82	-211	82	
41:12	45:54	282	TW457	L	94	83	11	83	-89	83	
44:25	47:28	183	WA215	L	87	110	-23	110	-65	110	*
46:23	48:55	152	N60MB	S	88	83	5	83	-80	83	
47:35	50:23	168	CO24	L	86	82	4	82	-90	82	
48:53	51:49	176	WA485	L	65	76	-11	76	-200	76	
48:29	52:54	265	UA280	H	133	134	-1	134	-24	134	
52:30	55:07	157	FL407	L	74	82	-8	82	-152	82	
52:35	56:21	226	WA554	L	83	83	0	83	-106	83	
54:35	57:44	189	BN990	L	79	77	2	77	-147	77	
55:17	59:03	226	UA182	H	141	137	4	137	-130	137	*
56:53	01:24	271	CO420	L	80	83	-3	83	-181	83	*
58:23	02:44	261	UA408	L	174	180	-6	180	-33	180	*
02:11	05:38	207	N743JA	S	82	76	6	76	9	76	
05:47	07:00	73	CO964	H	157	135	22	135	83	135	
08:23	09:37	74	UA226	L	125	108	17	83	108	83	**
11:25	11:42	17	OZ991	L	73	82	-9	82	-2	82	
11:40	12:55	75	TW186	L	67	83	-16	83	15	83	
13:10	14:02	52	UA434	L	158	141	17	83	141	83	**
16:23	16:40	17	UA346	L	56	82	-26	82	-60	82	
15:40	17:36	116	UA174	L	189	177	12	153	177	153	**
20:33	20:45	12	N4643G	S	78	82	-4	82	50	82	
21:35	22:03	28	CO265	L	92	83	9	83	22	83	
22:25	23:35	70	TW193	L	310	290	20	83	290	83	**
28:25	28:45	20	TW219	L	235	224	11	76	224	76	**
32:29	32:40	11	UA210	H							

AD-A073 548 STERLING SYSTEMS INC WASHINGTON DC F/G 17/7

AN ASSESSMENT OF TERMINAL AIR TRAFFIC CONTROL (ATC) SYSTEM PERF--ETC(U)

MAR 79 H C WINTERMOYER, W PAILEN, D MEYER DOT-FA79WAI-012

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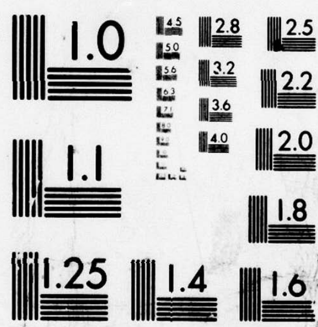

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table B-8

KEY MEASUREMENT VALUES - TEST RUN 8C
TRAFFIC SAMPLE D1741 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
15:30	15:37	7	WA55	L	115	100	15	87	100	87	**
17:17	17:32	15	BN62	L	228	222	6	100	222	100	**
21:14	21:20	6	FL884	L	74	84	-10	84	0	84	
21:20	22:34	74	CO721	L	122	101	21	101	9	101	
22:43	24:36	113	ASP416	L	74	84	-10	84	27	84	
25:03	25:50	47	UA927	L	100	86	14	86	78	86	
27:08	27:30	22	CO25	L	94	85	9	85	64	85	
28:34	29:04	30	WA53	L	88	86	2	86	59	86	
30:03	30:32	29	UA751	L	103	86	17	86	-72	86	
29:20	32:15	175	TI2888	L	79	85	-6	85	-41	85	
31:34	33:34	120	UA175	L	208	201	7	201	-57	201	
32:37	37:02	265	RMA217	S	84	85	-1	85	-239	85	
33:03	38:26	323	UA1423	L	88	85	3	85	-217	85	
34:49	39:54	305	UA161	L	91	86	5	86	-272	86	
35:22	41:25	363	TW173	L	93	86	7	86	-273	86	
36:52	42:58	366	TW457	L	94	113	-19	113	-28	113	*
42:30	44:32	122	N60MB	S	89	85	4	85	-106	85	
42:46	46:01	195	CO24	L	95	86	9	86	-121	86	
44:00	47:36	216	WA485	L	85	85	0	85	-93	85	
46:03	49:01	178	WA215	L	88	86	2	86	-274	86	
44:27	50:29	362	FL81	L	87	78	9	78	-167	78	
47:42	51:56	254	UA280	H	143	143	0	143	-47	143	
51:09	54:19	190	FL407	L	93	86	7	86	-153	86	
51:46	55:52	246	WA554	L	80	78	2	78	-93	78	
54:19	57:12	173	UA182	H	145	143	2	143	-72	143	
56:00	59:37	217	CO420	L	107	86	21	86	-127	86	
57:30	01:24	234	UA408	L	82	78	4	78	-155	78	
58:49	02:46	237	CO964	H	139	143	-4	143	-329	143	
57:17	05:05	468	BN990	L	92	86	6	86	-275	86	
00:30	06:37	367	UA226	L	92	85	7	85	-227	85	
02:50	08:09	319	TW186	L	88	85	3	85	-227	85	
04:22	09:37	315	UA434	L	190	179	11	179	-304	179	
04:33	12:47	494	N4643G	S	82	84	-2	84	-437	84	
05:30	14:09	519	UA346	L	87	86	1	86	-486	86	
06:03	15:36	573	OZ991	L					-523		*
06:53			N743JA	S							*
05:50	20:25	875	UA174	L	89	86	3	86	-562	86	
11:03	21:54	651	TW193	L	94	86	8	86	-531	86	
13:03	23:28	625	TW219	L	89	85	4	85	-671	85	
12:17	24:57	760	CO265	L	85	79	6	79	-375	79	
18:42	26:22	460	UA210	H							

Table B-9

KEY MEASUREMENT VALUES - TEST RUN 6D (-1)
TRAFFIC SAMPLE A2641 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
14:35	14:41	6	BN62	L	110	102	8	83	102	83	**
16:23	16:31	8	WA55	L	133	124	9	82	124	82	**
18:35	18:44	9	CO721	L	193	186	7	92	186	92	**
21:50	21:57	7	FL884	L	105	88	17	82	88	82	**
23:25	23:42	17	UA927	L	99	92	7	92	-22	92	
23:20	25:21	121	ASP416	L	88	82	6	82	9	82	
25:30	26:49	79	CO25	L	91	82	9	82	-14	82	
26:35	28:20	105	TI2888	L	188	174	14	84	174	84	**
31:14	31:28	14	WA53	L	74	83	-9	83	32	83	
32:00	32:42	42	UA751	L	115	89	26	82	89	82	**
34:11	34:37	26	UA175	L	132	105	27	83	105	83	**
36:22	36:49	27	UA1423	L	123	120	3	82	120	82	**
38:49	38:52	3	TW173	L	99	84	15	84	25	84	
39:17	40:31	74	UA161	L	77	83	-6	83	61	83	
41:32	41:48	16	TW457	L	171	177	-6	177	-109	177	
39:59	44:39	280	RMA217	S	93	103	-10	103	-174	103	
41:45	46:12	267	FL81	L	103	109	-6	109	21	109	*
46:33	47:55	82	N60MB	S	85	84	1	84	-210	84	
44:25	49:20	295	WA215	L	82	82	0	82	-98	82	
47:42	50:42	180	CO24	L	96	83	13	83	-109	83	
48:53	52:18	205	WA485	L	53	75	-22	75	-229	75	
48:29	53:11	282	UA280	H	131	135	-4	135	-41	135	
52:30	55:22	172	FL407	L	84	82	2	82	-167	82	
52:35	56:46	251	WA554	L	83	82	1	82	-131	82	
54:35	58:09	214	BN990	L	95	76	19	76	-172	76	
55:17	59:44	267	UA182	H	132	134	-2	134	-171	134	
56:53	01:56	303	CO420	L	83	82	1	82	-223	82	
58:13	03:19	306	UA408	L	220	177	43	177	-68	177	
02:11	06:59	288	N743JA	S	89	76	13	76	-36	76	
06:23	08:28	125	CO964	H	124	136	-12	136	8	136	
08:36	10:32	116	UA226	L	80	83	-3	83	57	83	
11:29	11:52	23	OZ991	L	77	82	-5	82	-7	82	
11:45	13:09	84	TW186	L	72	82	-10	82	36	82	
13:45	14:21	36	UA434	L	131	126	5	83	126	83	**
16:27	16:32	5	UA346	L	60	83	-23	83	-46	83	
15:46	17:32	106	UA174	L	229	207	22	157	207	157	**
20:59	21:21	22	N4643G	S	149	83	66	83	14	83	
21:35	23:50	135	CO265	L	77	82	-5	82	-85	82	
22:25	25:07	162	TW193	L	213	213	0	82	213	82	**
28:40	28:40	0	TW219	L	232	232	0	76	232	76	**
32:32	32:32	0	UA210	H							

Table B-10

KEY MEASUREMENT VALUES - TEST RUN 6D (-2)
TRAFFIC SAMPLE A2641 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght	Cat.	ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
14:35	14:41	6	BN62	L	110	102	8	83	102	83	**
16:23	16:31	8	WA55	L	133	124	9	82	124	82	**
18:35	18:44	9	CO721	L	193	186	7	92	186	92	**
21:50	21:57	7	FL884	L	105	88	17	82	88	82	**
23:25	23:42	17	UA927	L	99	92	7	92	-22	92	
23:20	25:21	121	ASP416	L	88	82	6	82	9	82	
25:30	26:49	79	CO25	L	91	82	9	82	-14	82	
26:35	28:20	105	T12888	L	188	174	14	84	174	84	**
31:14	31:28	14	WA53	L	74	83	-9	83	32	83	
32:00	32:42	42	UA751	L	115	89	26	82	89	82	**
34:11	34:37	26	UA175	L	132	105	27	83	105	83	**
36:22	36:49	27	UA1423	L	123	120	3	82	120	82	**
38:49	38:52	3	TW173	L	99	84	15	84	25	84	
39:17	40:31	74	UA161	L	77	83	-6	83	61	83	
41:32	41:48	16	TW457	L	171	177	-6	177	67	177	
42:55	44:39	104	RMA217	S	93	103	-10	103	-9	103	
44:30	46:12	102	FL81	L	103	109	-6	109	21	109	*
46:33	47:55	82	N60MB	S	85	84	1	84	-38	84	
47:17	49:20	123	WA215	L	82	82	0	82	-98	82	
47:42	50:42	180	CO24	L	96	83	13	83	-13	83	
50:29	52:18	109	WA485	L	53	75	-22	75	-111	75	
50:27	53:11	164	UA280	H	131	135	-4	135	84	135	
54:35	55:22	47	FL407	L	84	82	2	82	-37	82	
54:45	56:46	121	WA554	L	83	82	1	82	-5	82	
56:41	58:09	88	BN990	L	95	76	19	76	-46	76	
57:23	59:44	141	UA182	H	132	134	-2	134	53	134	
00:37	01:56	79	CO420	L	83	82	1	82	37	82	
02:33	03:19	46	UA408	L	220	208	12	177	208	177	**
06:47	06:59	12	N743JA	S	89	76	13	76	-36	76	
06:23	08:28	125	CO964	H	124	136	-12	136	8	136	
08:36	10:32	116	UA226	L	80	83	-3	83	57	83	
11:29	11:52	23	OZ991	L	77	82	-5	82	-7	82	
11:45	13:09	84	TW186	L	72	82	-10	82	36	82	
13:45	14:21	36	UA434	L	131	126	5	83	126	83	**
16:27	16:32	5	UA346	L	60	83	-23	83	-46	83	
15:46	17:32	106	UA174	L	229	207	22	157	207	157	**
20:59	21:21	22	N4643G	S	149	142	7	83	142	83	**
23:43	23:50	7	CO265	L	77	82	-5	82	35	82	
24:25	25:07	42	TW193	L	213	213	0	82	213	82	**
28:40	28:40	0	TW219	L	232	232	0	76	232	76	**
32:32	32:32	0	UA210	H							

Table B-11

KEY MEASUREMENT VALUES - TEST RUN 8D (-1)
TRAFFIC SAMPLE D1741 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
15:30	15:32	2	WA55	L	141	105	36	86	105	86	**
17:17	17:53	36	BN62	L	207	201	6	101	201	101	**
21:14	21:20	6	FL884	L	93	84	9	84	0	84	
21:20	22:53	93	CO721	L	102	100	2	100	30	100	
23:23	24:35	72	ASP416	L	82	84	-2	84	62	84	
25:37	25:57	20	UA927	L	95	86	9	86	70	86	
27:07	27:32	25	CO25	L	116	94	22	86	94	86	**
29:06	29:28	22	WA53	L	86	85	1	85	43	85	
30:11	30:54	43	UA751	L	92	86	6	86	70	86	
32:04	32:26	22	UA175	L	84	85	-1	85	41	85	
33:07	33:50	43	UA1423	L	90	87	3	87	-270	87	
29:20	35:20	360	TI2888	L	94	86	8	86	-15	86	
35:05	36:54	109	UA161	L	204	198	6	198	-257	198	
32:37	40:18	461	RMA217	S	86	85	1	85	-296	85	
35:22	41:44	382	TW173	L	90	85	5	85	-292	85	
36:52	43:14	382	TW457	L	90	110	-20	110	-35	110	*
42:39	44:44	125	N60MB	S	116	87	29	87	-44	87	
44:00	46:40	160	WA485	L	94	85	9	85	-234	85	
42:46	48:14	328	CO24	L	78	86	-8	86	-131	86	
46:03	49:32	209	WA215	L	98	85	13	85	-305	85	
44:27	51:10	403	FL81	L	90	78	12	78	-208	78	
47:42	52:40	298	UA280	H	174	143	31	143	-91	143	
51:09	55:34	265	FL407	L	95	88	7	88	-228	88	
51:46	57:09	323	WA554	L	78	78	0	78	-170	78	
54:19	58:27	248	UA182	H	221	145	76	145	-57	145	
57:30	02:08	278	UA408	L	88	85	3	85	-368	85	
56:00	03:36	456	CO420	L	111	77	34	77	-287	77	
58:49	05:27	398	CO964	H	139	143	-4	143	-490	143	
57:17	07:46	629	BN990	L	94	87	7	87	-296	87	
02:50	09:20	390	TW186	L	85	84	1	84	-530	84	
00:30	10:45	615	UA226	L	179	184	-5	184	-372	184	
04:33	13:44	551	N4643G	S	96	84	12	84	-461	84	
06:03	15:20	557	OZ991	L	88	87	1	87	-590	87	
05:30	16:48	678	UA346	L	82	84	-2	84	-746	84	
04:22	18:10	828	UA434	L	219	211	8	211	-677	211	
06:53	21:49	896	N743JA	S	80	84	-4	84	-959	84	
05:50	23:09	1039	UA174	L	88	87	1	87	-726	87	
11:03	24:37	814	TW193	L	125	85	40	85	-694	85	
13:03	26:42	819	TW219	L	84	86	-2	86	-865	86	
12:17	28:06	949	CO265	L	148	77	71	77	-564	77	
18:42	30:34	712	UA210	H							

Table B-12

KEY MEASUREMENT VALUES - TEST RUN 8D (-2)

TRAFFIC SAMPLE D1741 WITH BASIC M&S AUTOMATION

ETAR	ATAR	Delay	Ident. & Wght Cat.		ALTI	OLTI	LTI Err.	FSTC	NDTC	Adjusted OLTI	
15:30	15:32	2	WA55	L	141	105	36	86	105	86	**
17:17	17:53	36	BN62	L	207	201	6	101	201	101	**
21:14	21:20	6	FL884	L	93	84	9	84	0	84	
21:20	22:53	93	CO721	L	102	100	2	100	30	100	
23:23	24:35	72	ASP416	L	82	84	-2	84	62	84	
25:37	25:57	20	UA927	L	95	86	9	86	70	86	
27:07	27:32	25	CO25	L	116	94	22	86	94	86	**
29:06	29:28	22	WA53	L	86	85	1	85	43	85	
30:11	30:54	43	UA751	L	92	86	6	86	70	86	
32:04	32:26	22	UA175	L	84	85	-1	85	41	85	
33:07	33:50	43	UA1423	L	90	87	3	87	-90	87	
32:20	35:20	180	TI2888	L	94	86	8	86	-15	86	
35:05	36:54	109	UA161	L	204	198	6	198	-11	198	
36:43	40:18	215	RMA217	S	86	85	1	85	-43	85	
39:35	41:44	129	TW173	L	90	85	5	85	-80	85	
40:24	43:14	170	TW457	L	90	110	-20	110	-35	110	*
42:39	44:44	125	N60MB	S	116	116	0	87	116	87	**
46:40	46:40	0	WA485	L	94	85	9	85	-46	85	
45:54	48:14	140	CO24	L	78	86	-8	86	48	86	
49:02	49:32	30	WA215	L	98	85	13	85	-66	85	
48:26	51:10	164	FL81	L	90	78	12	78	-21	78	
50:49	52:40	111	UA280	H	174	151	23	143	151	143	**
55:11	55:34	23	FL407	L	95	88	7	88	-101	88	
53:53	57:09	196	WA554	L	78	78	0	78	22	78	
57:31	58:27	56	UA182	H	221	221	0	145	221	145	**
02:08	02:08	0	UA408	L	88	85	3	85	-2	85	
02:06	03:36	90	CO420	L	111	111	0	77	111	77	**
05:27	05:27	0	CO964	H	139	143	-4	143	-45	143	
04:42	07:46	184	BN990	L	94	87	7	87	20	87	
08:06	09:20	74	TW186	L	85	84	1	84	-46	84	
08:34	10:45	131	UA226	L	179	184	-5	184	39	184	
11:24	13:44	140	N4643G	S	96	84	12	84	15	84	
13:59	15:20	81	OZ991	L	88	87	1	87	-42	87	
14:38	16:48	130	UA346	L	82	84	-2	84	66	84	
17:54	18:10	16	UA434	L	219	211	8	211	49	211	
18:29	21:49	170	N743JA	S	80	84	-4	84	-115	84	
19:54	23:09	195	UA174	L	88	87	1	87	10	87	
23:19	24:37	78	TW193	L	125	98	27	85	98	85	**
26:15	26:42	27	TW219	L	84	86	-2	86	-147	86	
24:15	28:06	231	CO265	L	148	148	0	77	148	77	**
30:34	30:34	0	UA210	H							

APPENDIX C

FINAL APPROACH SPACING BY INDIVIDUAL TEST RUN

APPENDIX C

FINAL APPROACH SPACING BY INDIVIDUAL TEST RUN

- Explanatory Notes -

The tables contained in this appendix present data concerning the final approach spacing minimums between successive aircraft. The line entries following a particular aircraft identification apply to the spacing between that aircraft and the next aircraft in the list.

The asterisks identify intervals that were excluded from statistical summaries, histograms and bar graphs. These are for the same intervals and for the same reasons as the excluded intervals identified in Appendix B.

Under the general heading "Minimum Spacing", the column entries are expressed in nautical miles and represent the following:

> *"Required" is the minimum required spacing based on the weight class of each of the aircraft in the pair.*
>
> *"Experienced" is the minimum spacing actually experienced between the time the preceding aircraft of the pair crossed its gate and the time it reached the runway threshold.*

Under the heading "Difference", the column entries represent the plus or minus difference, in nautical miles, when the minimum spacing experienced is compared with the minimum spacing required.

Table C-1

FINAL APPROACH SPACING - RUN 1

TRAFFIC SAMPLE A2638 WITHOUT BASIC M&S AUTOMATION

	Minimum Spacing		
Ident.	Required	Experienced	Difference
OZ979	3	3.87	0.87
FL103	3	3.59	0.59
CO266	3	4.65	1.65
UA456	3	3.90	0.90
UA832	3	3.99	0.99
UA718	3	3.54	0.54
TI992	3	4.13	1.13
WA472	3	3.66	0.66
CO724	3	4.19	1.19
BN982	3	3.70	0.70
UA223	5	4.88	-0.12
UA176	3	2.78	-0.22
UA799	3	2.79	-0.21
A94617	3	3.85	0.85
CO52	3	3.07	0.07
FL88	3	3.96	0.96
UA760	4	2.98	-1.02
N111WJ	3	3.58	0.58
BN86	3	3.07	0.07 *
CO45	3	3.34	0.34 *
CO989	3	4.93	1.93 **
OZ531	3	2.58	-0.42
WA219	3	4.05	1.05
UA946	3	3.25	0.25
TW561	3	3.31	0.31
TW185	3	4.48	1.48
UA730	5	4.69	-0.31
UA259	3	3.48	0.48
UA311	3	3.34	0.34
TW449	3	3.32	0.32
UA305	3	3.40	0.40
CO44	3	3.06	0.06
FL20	3	1.26	-1.74 *
V54298	3	3.59	0.59 *
BN109	3	5.09	2.09
WA483	3	3.33	0.33
TW401	3	4.48	1.48
FL21			

Table C-2

FINAL APPROACH SPACING - RUN 3

TRAFFIC SAMPLE A1738 WITHOUT BASIC M&S AUTOMATION

Ident.	Minimum Spacing Required	Minimum Spacing Experienced	Difference	
OZ979	3	4.65	1.65	
FL103	3	3.53	0.53	
UA456	3	3.14	0.14	
CO266	3	3.15	0.15	
UA718	3	3.93	0.93	
UA832	3	3.97	0.97	
UA472	3	3.34	0.34	
CO724	3	3.80	0.80	
TI992	3	4.05	1.05	
BN982	3	2.75	-0.25	
UA223	5	4.33	-0.67	
UA176	3	3.61	0.61	
UA799	3	4.44	1.44	
A94617	3	3.18	0.18	
CO52	3	3.13	0.13	
FL88	3	3.27	0.27	
UA760	3	3.69	0.69	
BN86	4	2.56	-1.44	
N111WJ	3	3.82	0.82	
CO989	3	3.16	0.16	
OZ531	3	6.97	3.97	*
WA219	3	3.60	0.60	
UA946	3	3.69	0.69	
UA730	5	4.12	-0.88	
TW185	3	3.97	0.97	
TW561	3	2.81	-0.19	
UA259	3	3.73	0.73	
UA311	3	2.58	-0.42	
CO44	3	3.66	0.66	
V54298	3	2.12	-0.88	
TW449	3	2.87	-0.13	
UA305	3	2.76	-0.24	
FL20	3	3.36	0.36	
WA483	3	3.87	0.87	
BN109	3	3.22	0.22	
TW401	3	3.68	0.68	
FL21				

Table C-3

FINAL APPROACH SPACING - RUN 5

TRAFFIC SAMPLE A2641 WITHOUT BASIC M&S AUTOMATION

	Minimum Spacing			
Ident.	Required	Experienced	Difference	
BN62	3	4.85	1.85	
WA55	3	3.68	0.68	
CO721	3	7.05	4.05	**
FL884	3	4.36	1.36	
ASP416	3	3.00	0.00	
UA927	3	3.66	0.66	
CO25	3	2.61	-0.39	
TI2888	3	4.47	1.47	**
WA53	3	3.20	0.20	**
UA751	3	6.68	3.68	**
UA175	3	6.49	3.49	**
UA1423	4	6.09	2.09	*
RMA217	3	0.82	-2.18	*
TW173	3	3.11	0.11	
UA161	3	3.22	0.22	
TW457	3	3.58	0.58	
FL81	3	3.65	0.65	
WA215	4	4.07	0.07	
N60MB	3	2.60	-0.40	
CO24	3	3.21	0.21	
UA280	5	4.23	-0.77	
WA485	3	3.63	0.63	
FL407	3	3.25	0.25	
WA554	3	3.62	0.62	
BN990	3	2.81	-0.19	
UA182	5	4.49	-0.51	
CO420	3	3.05	0.05	
UA408	4	3.58	-0.42	
N743JA	3	2.80	-0.20	
CO964	5	5.42	0.42	
UA226	3	4.00	1.00	
TW186	3	3.08	0.08	
OZ991	3	3.13	0.13	
UA434	3	4.03	1.03	
UA174	3	3.68	0.68	
UA346	4	5.57	1.57	**
N4643G	3	3.16	0.16	
CO265	3	3.11	0.11	
TW193	3	12.17	9.17	**
TW219	3	14.25	11.25	**
UA210				

Table C-4

FINAL APPROACH SPACING - RUN 7

TRAFFIC SAMPLE D1741 WITHOUT BASIC M&S AUTOMATION

	Minimum Spacing			
Ident.	Required	Experienced	Difference	
WA55	3	4.31	1.31	
BN62	3	5.00	2.00	**
FL884	3	2.58	-0.42	
CO721	3	2.58	-0.42	
ASP416	3	4.69	1.69	**
UA927	3	4.52	1.52	**
CO25	3	4.00	1.00	
TI2888	3	2.32	-0.68	
WA53	4	2.43	-1.57	*
RMA217	3	1.09	-1.91	*
UA751	3	2.92	-0.08	
UA175	3	2.77	-0.23	
UA1423	3	3.34	0.34	
UA161	3	2.83	-0.17	
TW173	3	3.35	0.35	
TW457	3	3.35	0.35	**
CO24	4	4.00	0.00	
N60MB	3	2.96	-0.04	
FL81	3	2.74	-0.26	
WA485	3	3.43	0.43	
WA215	3	3.06	0.06	
UA280	5	5.20	0.20	
FL407	3	3.88	0.88	
WA554	3	3.14	0.14	
UA182	5	4.51	-0.49	
CO420	3	3.66	0.66	
BN990	3	2.66	-0.34	
UA408	3	2.31	-0.69	
CO964	5	4.92	-0.08	
UA226	3	2.81	-0.19	
TW186	4	2.57	-1.43	
N4643G	3	3.68	0.68	*
OZ991	3	1.77	-1.23	
UA356	3	4.76	1.76	
UA434	3	5.26	2.26	*
UA174	3	2.74	-0.26	
CO265	3	2.52	-0.48	
TW193	3	3.65	0.65	
TW219	3	3.41	0.41	
UA210				

Table C-5

FINAL APPROACH SPACING - RUN 2C

TRAFFIC SAMPLE A2638 WITH BASIC M&S AUTOMATION

	Minimum Spacing			
Ident.	Required	Experienced	Difference	
OZ979	3	3.15	0.15	
FL103	3	2.76	-0.24	
CO266	3	4.46	1.46	**
UA456	3	4.23	1.23	**
UA718	3	2.06	-0.94	
UA832	3	3.41	0.41	
TI992	3	4.36	1.36	**
CO724	3	2.34	-0.66	
WA472	3	4.73	1.73	**
BN982	3	6.12	3.12	**
UA223	5	4.71	-0.29	
UA799	3	3.44	0.44	
A95617	3	2.80	-0.20	
UA176	3	2.90	-0.10	
CO52	3	3.45	0.45	
FL88	3	3.43	0.43	
UA760	4	3.53	-0.47	
N111WJ	3	2.86	-0.14	
BN86	3	3.36	0.36	**
CO45	3	3.52	0.52	**
CO989	3	6.04	3.04	**
OZ531	3	3.09	0.09	
WA219	3	3.57	0.57	
UA946	3	2.87	-0.13	
TW561	3	2.72	-0.28	
TW185	3	3.00	0.00	
UA730	5	6.08	1.08	**
UA259	3	3.01	0.01	
UA311	3	3.35	0.35	
TW449	3	3.38	0.38	**
UA305	3	3.21	0.21	
CO44	3	3.30	0.30	
V54298	3	3.52	0.52	**
BN109	3	3.26	0.26	
FL20	3	5.48	2.48	**
WA483	3	3.67	0.67	**
TW401	3	4.01	1.01	**
FL21				

Table C-6

FINAL APPROACH SPACING - RUN 4C
TRAFFIC SAMPLE A1738 WITH BASIC M&S AUTOMATION

Ident.	Minimum Spacing Required	Minimum Spacing Experienced	Difference	
OZ979	3	3.11	0.11	
FL103	3	3.45	0.45	
UA456	3	3.25	0.25	
UA718	3	2.93	-0.07	
CO266	3	3.59	0.59	
UA832	3	3.97	0.97	**
CO724	3	3.04	0.04	
WA472	3	9.75	6.75	**
UA223	5	5.77	0.77	
TI992	3	3.17	0.17	
BN982	3	3.13	0.13	
UA176	3	3.23	0.23	
UA799	3	3.09	0.09	
A94617	3	3.68	0.68	
CO52	3	3.61	0.61	
FL88	3	2.96	-0.04	
UA760	4	4.30	0.30	
N111WJ	3	3.16	0.16	
BN86	3	3.49	0.49	
OZ531	3	3.09	0.09	
CO989	3	3.30	0.30	
WA219	3	3.95	0.95	
CO45	3	3.62	0.62	
UA946	3	2.91	-0.09	
UA730	5	4.90	-0.10	
TW185	3	3.84	0.84	
UA259	3	3.18	0.18	
UA311	3	3.02	0.02	
TW561	3	3.28	0.28	
CO44	3	4.49	1.49	
V54298	3	3.15	0.15	
TW449	3	3.74	0.74	
UA305	3	3.08	0.08	
FL20	3	3.61	0.61	
WA483	3	2.88	-0.12	
BN109	3	3.17	0.17	
TW401	3	3.35	0.35	
FL21				

Table C-7

FINAL APPROACH SPACING - RUN 6C
TRAFFIC SAMPLE A2641 WITH BASIC M&S AUTOMATION

Ident.	Minimum Spacing Required	Minimum Spacing Experienced	Difference	
BN62	3	3.81	0.81	**
WA55	3	5.08	2.08	**
CO721	3	7.42	4.42	**
FL884	3	3.67	0.67	
UA927	3	2.67	-0.33	
ASP416	3	3.33	0.33	
CO25	3	2.75	-0.25	
TI2888	3	7.20	4.20	**
WA53	3	2.63	-0.37	
UA751	3	4.28	1.28	**
UA175	3	5.62	2.62	**
UA1423	3	4.85	1.85	**
TW173	3	3.87	0.87	
UA161	4	3.12	-0.88	
RMA217	3	3.08	0.08	
FL81	3	2.60	-0.40	
TW457	3	3.41	0.41	
WA215	4	3.16	-0.84	*
N60MB	3	3.17	0.17	
CO24	3	3.14	0.14	
WA485	3	2.57	-0.43	
UA280	5	4.94	-0.06	
FL407	3	2.69	-0.31	
WA554	3	3.01	0.01	
BN990	3	3.09	0.09	
UA182	5	5.18	0.18	*
CO420	3	2.88	-0.12	*
UA408	4	3.76	-0.24	*
N743JA	3	3.25	0.25	
CO964	5	6.00	1.00	
UA226	3	4.57	1.57	**
OZ991	3	2.66	-0.34	
TW186	3	2.43	-0.57	
UA434	3	6.07	3.07	**
UA346	3	2.05	-0.95	
UA174	4	5.28	1.28	**
N4643G	3	2.87	-0.13	
CO265	3	3.34	0.34	
TW193	3	14.12	11.12	**
TW219	3	10.37	7.37	**
UA210				

Table C-8

FINAL APPROACH SPACING - RUN 8C
TRAFFIC SAMPLE D1741 WITH BASIC M&S AUTOMATION

Ident.	Minimum Spacing Required	Minimum Spacing Experienced	Difference	
WA55	3	4.00	1.00	**
BN62	3	7.86	4.86	**
FL884	3	2.64	-0.36	
CO721	3	3.73	0.73	
ASP416	3	2.65	-0.35	
UA927	3	3.48	0.48	
CO25	3	3.32	0.32	
WA53	3	3.08	0.08	
UA751	3	3.60	0.60	
TI2888	3	2.77	-0.23	
UA175	4	4.24	0.24	
RMA217	3	2.97	-0.03	
UA1423	3	3.10	0.10	
UA161	3	3.19	0.19	
TW173	3	3.27	0.27	
TW457	4	3.27	-0.73	*
N60MB	3	3.15	0.15	
CO24	3	3.31	0.31	
WA485	3	3.01	0.01	
WA215	3	3.08	0.08	
FL81	3	3.34	0.34	
UA280	5	4.98	-0.02	
FL407	3	3.24	0.24	
WA554	3	3.09	0.09	
UA182	5	5.07	0.07	
CO420	3	3.75	0.75	
UA408	3	3.16	0.16	
CO964	5	4.82	-0.18	
BN990	3	3.23	0.23	
UA226	3	3.23	0.23	
TW186	3	3.11	0.11	
UA434	4	4.40	0.40	
N4643G	3	2.92	-0.08	
UA346	3	3.04	0.04	
OZ991	4			*
N743JA	3			*
UA174	3	3.12	0.12	
TW193	3	3.29	0.29	
TW219	3	3.15	0.15	
CO265	3	3.23	0.23	
UA210				

Table C-9

FINAL APPROACH SPACING - RUN 6D (-1)
TRAFFIC SAMPLE A2641 WITH BASIC M&S AUTOMATION

	Minimum Spacing			
Ident.	Required	Experienced	Difference	
BN62	3	3.99	0.99	**
WA55	3	4.94	1.94	**
CO721	3	7.17	4.17	**
FL884	3	3.83	0.83	**
UA927	3	3.26	0.26	
ASP416	3	3.21	0.21	
CO25	3	3.35	0.35	
TI2888	3	7.37	4.37	**
WA53	3	2.69	-0.31	
UA751	3	4.21	1.21	**
UA175	3	4.88	1.88	**
UA1423	3	4.52	1.52	**
TW173	3	3.58	0.58	
UA161	3	2.78	-0.22	
TW457	4	3.76	-0.24	
RMA217	3	3.35	0.35	
FL81	4	3.77	-0.23	*
N60MB	3	3.06	0.06	
WA215	3	3.00	0.00	
CO24	3	3.46	0.46	
WA485	3	2.12	-0.88	
UA280	5	4.84	-0.16	
FL407	3	3.06	0.06	
WA554	3	3.04	0.04	
BN990	3	3.77	0.77	
UA182	5	4.90	-0.10	
CO420	3	3.05	0.05	
UA408	4	5.56	1.56	
N743JA	3	3.52	0.52	
CO964	5	4.49	-0.51	
UA226	3	2.90	-0.10	
OZ991	3	2.81	-0.19	
TW186	3	2.62	-0.38	
UA434	3	4.77	1.77	**
UA346	3	2.15	-0.85	
UA174	4	6.65	2.65	**
N4643G	3	5.59	2.59	
CO265	3	2.82	-0.18	
TW193	3	8.17	5.17	**
TW219	3	9.91	6.91	**
UA210				

Table C-10

FINAL APPROACH SPACING - RUN 6D (-2)
TRAFFIC SAMPLE A2641 WITH BASIC M&S AUTOMATION

Ident.	Minimum Spacing Required	Experienced	Difference	
BN62	3	3.99	0.99	**
WA55	3	4.94	1.94	**
CO721	3	7.17	4.17	**
FL884	3	3.83	0.83	**
UA927	3	3.26	0.26	
ASP416	3	3.21	0.21	
CO25	3	3.35	0.35	
TI2888	3	7.37	4.37	**
WA53	3	2.69	-0.31	
UA751	3	4.21	1.21	**
UA175	3	4.88	1.88	**
UA1423	3	4.52	1.52	**
TW173	3	3.58	0.58	
UA161	3	2.78	-0.22	
TW457	4	3.76	-0.24	
RMA217	3	3.35	0.35	
FL81	4	3.77	-0.23	*
N60MB	3	3.06	0.06	
WA215	3	3.00	0.00	
CO24	3	3.46	0.46	
WA485	3	2.12	-0.88	
UA280	5	4.84	-0.16	
FL407	3	3.06	0.06	
WA554	3	3.04	0.04	
BN990	3	3.77	0.77	
UA182	5	4.90	-0.10	
CO420	3	3.05	0.05	
UA408	4	5.56	1.56	**
N743JA	3	3.52	0.52	
CO964	5	4.49	-0.51	
UA226	3	2.90	-0.10	
OZ991	3	2.81	-0.19	
TW186	3	2.62	-0.38	
UA434	3	4.77	1.77	**
UA346	3	2.15	-0.85	
UA174	4	6.65	2.65	**
N4643G	3	5.59	2.59	**
CO265	3	2.82	-0.18	
TW193	3	8.17	5.17	**
TW219	3	9.91	6.91	**
UA210				

Table C-11

FINAL APPROACH SPACING - RUN 8D (-1)
TRAFFIC SAMPLE D1741 WITH BASIC M&S AUTOMATION

Ident.	Minimum Spacing Required	Minimum Spacing Experienced	Difference	
WA55	3	5.00	2.00	**
BN62	3	6.94	3.94	**
FL884	3	3.32	0.32	
CO721	3	3.06	0.06	
ASP416	3	2.92	-0.08	
UA927	3	3.30	0.30	
CO25	3	4.07	1.07	**
WA53	3	3.04	0.04	
UA751	3	3.22	0.22	
UA175	3	2.97	-0.03	
UA1423	3	3.17	0.17	
TI2888	3	3.29	0.29	
UA161	4	4.21	0.21	
RMA217	3	3.03	0.03	
TW173	3	3.16	0.16	
TW457	4	3.18	-0.82	*
N60MB	3	4.02	1.02	
WA485	3	3.33	0.33	
CO24	3	2.70	-0.30	
WA215	3	3.46	0.46	
FL81	3	3.45	0.45	
UA280	5	6.19	1.19	
FL407	3	3.27	0.27	
WA554	3	3.00	0.00	
UA182	5	8.17	3.17	
UA408	3	3.09	0.09	
CO420	3	4.28	1.28	
CO964	5	4.83	-0.17	
BN990	3	3.26	0.26	
TW186	3	3.02	0.02	
UA226	4	3.81	-0.19	
N4643G	3	3.43	0.43	
OZ991	3	3.03	0.03	
UA346	3	2.92	-0.08	
UA434	4	4.29	0.29	
N743JA	3	2.86	-0.14	
UA174	3	3.03	0.03	
TW193	3	4.40	1.40	
TW219	3	2.94	-0.06	
CO265	3	5.68	2.68	
UA210				

Table C-12

FINAL APPROACH SPACING - RUN 8D (-2)
TRAFFIC SAMPLE D1741 WITH BASIC M&S AUTOMATION

Ident.	Minimum Spacing Required	Minimum Spacing Experienced	Difference	
WA55	3	5.00	2.00	**
BN62	3	6.94	3.94	**
FL884	3	3.32	0.32	
CO721	3	3.06	0.06	
ASP416	3	2.92	-0.08	
UA927	3	3.30	0.30	
CO25	3	4.07	1.07	**
WA53	3	3.04	0.04	
UA751	3	3.22	0.22	
UA175	3	2.97	-0.03	
UA1423	3	3.17	0.17	
TI2888	3	3.29	0.29	
UA161	4	4.21	0.21	
RMA217	3	3.03	0.03	
TW173	3	3.16	0.16	
TW457	4	3.18	-0.82	*
N60MB	3	4.02	1.02	**
WA485	3	3.33	0.33	
CO24	3	2.70	-0.30	
WA215	3	3.46	0.46	
FL81	3	3.45	0.45	
UA280	5	6.19	1.19	**
FL407	3	3.27	0.27	
WA554	3	3.00	0.00	
UA182	5	8.17	3.17	**
UA408	3	3.09	0.09	
CO420	3	4.28	1.28	**
CO964	5	4.83	-0.17	
BN990	3	3.26	0.26	
TW186	3	3.02	0.02	
UA226	4	3.81	-0.19	
N4643G	3	3.43	0.43	
OZ991	3	3.03	0.03	
UA346	3	2.92	-0.08	
UA434	4	4.29	0.29	
N743JA	3	2.86	-0.14	
UA174	3	3.03	0.03	
TW193	3	4.40	1.40	**
TW219	3	2.94	-0.06	
CO265	3	5.68	2.68	**
UA210				

APPENDIX D

KURTOSIS AND SKEWNESS MEASUREMENTS

APPENDIX D

KURTOSIS AND SKEWNESS MEASUREMENTS

Table D-1 lists the statistical characteristics of the LTI error distributions of all separate and combined samples used in the analyses. This appendix is concerned with the kurtosis and skewness measurements in the last two columns of the table.

The kurtosis is a quantity which is used to interpret the flatness or peakedness of a distribution curve; the kurtosis for a normal distribution is 3.00. The skewness is used as a measure of symmetry; the skewness of a normal distribution is zero, and a distribution is generally considered to be symmetric when the magnitude of its skewness does not exceed 1/2.

Values of kurtosis and skewness for single samples 1,3,5,7--and 2C,4C,6C,8C--may be considered to be individual measurements of the kurtosis and skewness of the parent populations from which they are drawn. The means and standard deviations of these measurements are summarized in Table D-2. The mean kurtosis values both lie within 1 standard deviation of 3.00, indicating normal distributions; and the mean skewness values both lie within 1 standard deviation of zero, which also indicates normal distributions. By this argument, these two parent populations--of the normal case and of the unmetered M & S case--may be conidered to be normally distributed.

The situation is different in the case of the metered runs. The (-1) runs and their combination all have values of kurtosis greater than 7 and values of skewness greater than 1. In addition, the combined (-2) sample shows significant assymmetry, since the magnitude of its skewness is greater than 1/2. These measures do not support the assumption that the parent populations are normal.

TABLE D-1

STATISTICAL CHARACTERISTICS OF LTI ERROR DISTRIBUTIONS

Sample Identity	Size	Mean	Standard Deviation N wt.	Variance (N-1) wt.	Kurtosis	Skewness
1	32	14.22	16.42	278.37	3.24	.024
2C	23	0.09	10.04	105.45	3.15	-.688
3	35	9.26	16.92	294.67	3.00	-.439
4C	35	8.49	8.49	74.26	2.44	.636
5	30	7.57	13.68	193.50	2.64	.304
6C	24	-0.83	12.42	160.93	2.54	.154
6D-1	27	2.93	17.91	334.10	7.02	1.794
6D-2	25	-1.20	10.30	110.42	2.77	-.093
7	31	0.71	17.91	331.35	3.57	.396
8C	35	4.60	6.96	49.89	3.56	.283
8D-1	36	10.47	18.72	360.31	7.62	2.229
8D-2	30	3.20	5.41	30.23	2.13	-.003
5,7	61	4.08	16.33	271.14	3.37	.196
6C,8C	59	2.39	9.93	100.31	3.43	-.252
6D-1,8D-1	63	7.24	18.75	357.25	7.31	1.959
6D-2,8D-2	55	1.20	8.30	70.20	3.72	-.524
1,3,5,7	128	8.03	17.04	292.49	3.09	-.017
2C,4C,6C, 8C	117	3.76	10.07	102.29	3.60	-.236

TABLE D-2

MEASURES OF KURTOSIS AND SKEWNESS OF PARENT POPULATIONS

Sample	Kurtosis	Skewness
1	3.25	.024
3	3.00	-.439
5	2.64	.304
7	3.57	.396
Mean	3.12	.072
S.D.	.39	.375
2C	3.15	-.688
4C	2.44	.636
6C	2.54	.154
8C	3.56	.283
Mean	2.92	.096
S.D.	.53	.561

APPENDIX E

GOODNESS-OF-FIT CHI-SQUARE TESTS

APPENDIX E

GOODNESS-OF-FIT CHI-SQUARE TESTS

Histograms were prepared from combined samples (1,3,5,7) and (2C,4C,6C,8C). Theoretical cell frequences, of normal distributions having the same mean and standard deviation as the combined sample, were calculated. These frequences were compared with the observed frequencies, and χ^2,

$$= \sum_{\text{cells}}^{\text{all}} \frac{(f_{\text{observed}} - f_{\text{theoretical}})^2}{f_{\text{theoretical}}}$$

was calculated. This quantity is a measure of the discrepancies between the theoretical and observed frequences, a larger χ^2 indicating larger discrepancies. The probability distribution of this function , $P(\chi^2)$, is the probability that a sample taken from a normally distributed parent population will have less discrepancies from the theoretical frequencies than the combined sample histogram.

The test results are listed in Table E-1. In the case of the combined manual runs, with $P(\chi^2) = 0.09$, it means that only 9% of the samples (of the same size as the (1,3,5,7) combination) drawn from a normally distributed parent population will have smaller χ^2 values and thus smaller discrepancies than those exhibited by (1,3,5,7). Ninety-one percent, or approximately 9 out of 10 samples drawn from normal parents will have larger discrepancies than those discrepancies exhibited by (1,3,5,7). But in the case of (2C,4C,6C,8C), with a $P(\chi^2) = 0.99$, it means that only 1% (or 1 out of every 100) samples of the same size drawn from a normally distributed parent population will have larger discrepancies than those exhibited by (2C,4C,6C,8C).

TABLE E-1

CHI-SQUARE TEST RESULTS

A. COMBINED MANUAL RUNS (1,3,5,7); Mean = 8.03, S. D. = 17.10

Histogram Cell	Observed Frequency	Theoretical Frequency	$\frac{(f_o - f_{th})^2}{f_{th}}$
1(-oo to -10)	18	18.67	.024
2(-10 to 0)	21	22.20	.065
3(0 to 10)	30	29.00	.035
4(10 to 20)	28	27.16	.026
5(20 to 30)	20	18.24	.169
6(30 to oo)	11	12.73	.234
Totals	128	128.00	.553 = χ^2

Degress of freedom (d. f.) = # of cells - 3 = 3
(Three degrees of freedom are lost; one in the selection of cell boundaries, the other two in using the sample mean and standard deviation to calculate theoretical frequencies.)

$P(\chi^2) = 0.09$, for d. f. = 3.

TABLE E-1 (Continued)

CHI-SQUARE TEST RESULTS

B. COMBINED UNMETERED M & S RUNS (2C,4C,6C,8C);
Mean = 3.76, S. D. = 10.11

Histogram Cell	Observed Frequency	Theoretical Frequency	$\frac{(f_o - f_{th})^2}{f_{th}}$
1(-oo to -10)	8	10.15	.455
2(-10 to 0)	25	31.38	1.298
3(0 to 10)	58	44.05	4.420
4(10 to 20)	18	25.09	2.004
5(20 to oo)	8	6.33	.441
Totals	117	117.00	8.618 = χ^2

Degrees of freedom = # of cells - 3 = 2

$P(\chi^2)$ = 0.99, for d. f. = 2.

APPENDIX F

F-TEST OF VARIANCE

APPENDIX F

F-TEST OF VARIANCE

The ratio of variances (= F) of the two samples being compared follows a known distribution function P(F), which depends only upon the value of F and the degrees of freedom of each variance. This function has been calculated for each sample comparison made and listed in Table F-1 below.

The hypothesis being tested is the "null hypothesis", the hypothesis that the sample points in both samples have been drawn from the same parent population and that differences in the observed sample variances were due to chance alone. Rejection of this hypothesis implies that something other than chance had produced the observed differences. An 80% level of confidence in the rejection of this hypothesis, for example, would be achieved by rejected the null hypothesis for differences whose P-value was grater than 90% and less than 10%, both "tails" of the P-function being cut off.

In the case of a sample comparison whose P = 90.6% (as in (6C,8C) vs. (6D-2,8d-2)), 9.4% of the comparisons made with samples of the same size drawn from the same normal population would exhbit larger variance ratios than the variance ratio from this particular sample comparison. But there would also be variance ratios with P-values less than 9.4% which would also be eliminated; a level of confidence whose upper boundary is set at 90.6% will have a lower boundary at 9.4%. The level of confidence for this case is therefore 90.6 - 9.4 = 81.2%, or approximately 80%. The other confidence levels found in this test were all greater than 99%.

TABLE F-1

COMPARISON OF SAMPLE VARIANCE BY F-TEST

SAMPLE 1			SAMPLE 2					
Identity	Variance	df	Identity	Variance	df	F	P(F)	Confidence level below which the variances differ significantly
(1,3,5,7)	292.49	127	(2C,4C,6C,8C)	102.29	116	2.85	0.999	99%
(5,7)	271.14	60	(6C,8C)	100.31	58	2.70	0.999	99%
(6D-1,8D-1)	357.25	62	(6C,8C)	100.31	58	3.56	0.999	99%
(6D-1,8D-1)	357.25	62	(6D-2,8D-2)	70.20	54	5.09	0.999	99%
(6C,8C)	100.31	58	(6D-2,8D-2)	70.20	54	1.43	0.906	80%
(5,7)	271.14	60	(6D-2,8D-2)	70.20	54	3.68	0.999	99%

df = degrees of freedom

APPENDIX G

MILLER JACKKNIFE TEST OF VARIANCE

APPENDIX G

MILLER JACKKNIFE TEST OF VARIANCE

This test works with linear combinations of the natural logarithms of the array of sample variances produced by deleting one point from the sample; each choice of the point deleted produces a different variance.[3] These linear combinations are assumed to be normally distributed, and the differences between the mean values of the linear combinations are tested for significance in a manner analogous to the t-test (Appendix H discusses the t-test).

For samples x_i with m values and y_i with n values, governing equations are listed below:

$$S_j = \ln \frac{\Sigma(x_i - \overline{x})^2}{m-2}, \text{ where } \overline{x} = \frac{\Sigma x_i}{m-1}, \text{ the summations}$$

excluding the x_j point.

$$T_j = \ln \frac{\Sigma(y_i - \overline{y})^2}{n-2}, \text{ where } \overline{y} = \frac{\Sigma y_i}{n-1}, \text{ the summations}$$

excluding the y_j point.

$$S_o = \ln \frac{\Sigma(x_i - \overline{x})^2}{m-1} \quad \text{and } T_o = \ln \frac{\Sigma(y_i - \overline{y})^2}{n-1}$$

where in this case $\overline{x}$ and $\overline{y}$ represent the normal sample means and the summations are performed over all sample points. Then we compute

$$A_j = mS_o - (m-1)S_j \text{ and } B_j = nT_o - (n-1)T_j \quad \text{, and find}$$

their mean values $\overline{A}$ and $\overline{B}$ by averaging over all A_j, and B_j, and B_j in the normal way.

We then calculate

$$V_1 = \frac{\Sigma(A_j - \overline{A})^2}{m(m - 1)} \text{ and } V_2 = \frac{\Sigma(B_j - \overline{B})^2}{n(n - 1)},$$

and find the value of

$$z = \frac{\overline{A} - \overline{B}}{\sqrt{(V_1 + V_2)}},$$

which is assumed to be the z-value of a normal distribution, from which the probability distribution function P(z) is then calculated for each particular sample comparison.

Test results are summarized in Table G-1. Confidence levels are derived from the probability distribution P-values in the manner described in Appendix F.

TABLE G-1

COMPARISON OF SAMPLE VARIANCE
BY MILLER JACKKNIFE TESTS

SAMPLE 1				SAMPLE 2						
Identity	Variance	A	V_1	Identity	Variance	B	V_2	z	P(z)	Confidence level below which the variances differ significantly
(1,3,5,7)	292.49	5.69	.017	(2C,4C,6C,8C)	102.29	4.64	.023	5.17	.999	99%
(5,7)	271.14	5.62	.044	(6C,8C)	100.31	4.63	.046	3.30	.999	99%
(6D-1,8D-1)	357.25	5.94	.125	(6C,8C)	100.31	4.63	.046	3.16	.999	99%
(6D-1,8D-1)	357.25	5.94	.125	(6D-2,8D-2)	70.20	4.28	.058	3.88	.999	99%
(6C,8C)	100.31	4.63	.046	(6D-2,8D-2)	70.20	4.28	.058	1.09	.862	70%
(5,7)	271.14	5.62	.044	(6D-2,8D-2)	70.20	4.28	.058	4.21	.999	99%

APPENDIX H

t-TEST ON MEANS

APPENDIX H

t-TEST ON MEANS

The difference in means of samples drawn from a normally distributed population, when divided by their standard error, follows a known probability distribution function known as a t-distribution, which also depends upon the total degrees of freedom (minus two) of both samples. For a sample x_i of m points and a sample y_i of n points, the defining equation for the t-statistic is

$$t = \frac{\bar{x} - \bar{y}}{(1/m + 1/n)^{\frac{1}{2}} \left[\frac{\Sigma x_i^2 - m\bar{x}^2 + \Sigma y_i^2 - n\bar{y}^2}{m + n - 2}\right]^{\frac{1}{2}}}$$

The results of performing this test on the various combined sample comparisons are listed in Table H-1. Confidence levels are derived in the manner described in Appendix F.

TABLE H-1

COMPARISON OF SAMPLE MEANS BY t-TEST

SAMPLE 1		SAMPLE 2					Confidence level
Identity	Mean	Identity	Mean	Total df	t	P(t)	below which the means differed significantly
(1,3,5,7)	8.03	(2C,4C, 6C,8C)	3.76	243	2.304	.989	97.5%
(5,7)	4.08	(6C,8C)	2.39	118	.677	.750	50%
(6D-1,8D-1)	7.24	(6C,8C)	2.39	120	1.753	.959	90%
(6D-1,8D-1)	7.24	(6D-2,8D-2)	1.20	116	2.188	.985	95%
(6C,8C)	2.39	(6D-2,8D-2)	1.20	112	2.009	.975	95%
(5,7)	4.08	(6D-2,8D-2)	1.20	114	1.241	.891	75%

df = degrees of freedom

APPENDIX I

REFERENCES

APPENDIX I

REFERENCES

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